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# NATIONAL CROP LOSS ASSESSMENT NETWORK (NCLAN) 1980 ANNUAL REPORT

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16. ABSTRACT

U.S. field crop production is valued at more than $50 billion annually. Crops are known to be sensitive to air pollution stress. Even a small percentage reduction in crop yield due to air pollution exposure could cause billions of dollars in direct and secondary economic losses. The National Crop Loss Assessment Network (NCLAN) consists of a group of cooperating government and nongovernment organizations engaged in field work, crop modeling, and economic studies to assess immediate and long-term economic consequences of the effects of air pollution on crop production. The program will define the relationships between yields of major agricultural crops and doses of ozone, sulfur dioxide, nitrogen dioxide, and their mixtures using state-of-the-art technology in the field with realistic pollutant exposure regimes. These data will be used to assess the economic consequences of exposure of agricultural crops to these pollutants. The economic assessment will consider both environmental and economic factors. This assessment requires regionally averaged, time independent crop production data as a function of regional air quality for crops selected for study. The first regional crop response estimates will use an empirical correlation of a seasonal average 7-hr/day ozone concentration and resultant yield effects observed at a single site per region. Descriptive empirical models that estimate the effects of edaphic, climatic, and biological factors on the pollutant-induced yield effects will be developed as data become available. These models will become more mechanistically based with increased understanding.

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## ABSTRACT

U.S. field crop production is valued at more than $50 billion annually. Crops are known to be sensitive to air pollution stress. Even a small percentage reduction in crop yield due to air pollution exposure could cause billions of dollars in direct and secondary economic losses.

The National Crop Loss Assessment Network (NCLAN) consists of a group of cooperating government and nongovernment organizations engaged in field work, crop modeling, and economic studies to assess the immediate and long-term economic consequences of the effects of air pollution on crop production. The program will define the relationships between yields of major agricultural crops and doses of ozone, sulfur dioxide, nitrogen dioxide, and their mixtures using state-of-the-art technology in the field with realistic pollutant exposure regimes. These data will be used to assess the economic consequences of exposure of agricultural crops to these pollutants.

The economic assessment will consider both environmental and economic factors. This assessment requires regionally averaged, time independent crop production data as a function of regional air quality for crops selected for study. The first regional crop response estimates will use an empirical correlation of a seasonal average 7-hr/day ozone concentration and resultant yield effects observed at a single site per region. Descriptive empirical models that estimate the effects of edaphic, climatic, and biological factors on the pollutant-induced yield effects will be developed as data become available. These models will become more mechanistically based with increased understanding of pollutant-biological interactions.

The open-top chamber is the primary crop exposure facility. This chamber is well tested and permits control of gas(es) around the plant canopy so that specific pollution regimes can be imposed on the plants in dose-response experiments. The chambers have either minimal or no effect on the response of the crops growing within them.

The program intends to: 1) develop additional research sites; 2) assess producer and consumer economic costs; 3) study other biotic and environmental factors affecting crop response to pollutants; 4) assess the effects of pollutants on crop quality; and 5) expand the crop studies to other pollutants and pollutant mixtures.

This report was submitted in fulfillment of Interagency and Cooperative Agreements by the participating research groups under the sponsorship of the U.S. Environmental Protection Agency and discusses results achieved during the period from February 1, 1980 to January 31, 1981.

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# SECTION 1

## INTRODUCTION

The current ozone ($O_3$) and sulfur dioxide ($SO_2$) secondary National Ambient Air Quality Standards (NAAQS) are based on vegetation effects information presented in the Air Quality Criteria for Ozone and Other Photochemical Oxidants (1) and in the Air Quality Criteria for Sulfur Oxides (2). The comprehensive review of the appropriate literature presented in these documents illustrates that there is a need for additional controlled field studies of the effects of pollutant exposure on economically important crop plants at concentrations experienced in the United States.

During the 1970's, research has shown significant reductions in growth and yield of agricultural crops at air pollutant concentrations below the present standards (1, 2). However, few of these studies were designed to provide data suitable for the selection of NAAQS that protect crops from economic damage. Interpretive difficulties in applying the results of these studies include:

1. Few were performed with field crops grown according to common agronomic practices.

2. Experimental pollutant exposure regimes did not mimic anthropogenic exposure and may have substantially altered plant susceptibility to effects on growth and yield.

3. Plant response usually was evaluated in ways that were not easily converted to economic value.

While economic and related impacts are not currently considered in selecting the concentration(s) for secondary NAAQS, there is a clear need for better information in this area. Presently, EPA's Administrator provides an assessment of economic impacts associated with the promulgation of new or revised NAAQS as well as other air pollution control regulations on an annual basis. Such an assessment should not only estimate pollution control costs, but also economic benefits derived from cleaner air. The need for a reliable benefits analysis is especially evident when the estimated costs of pollution control are examined. For example, in 1979, EPA estimated the annual cost of achieving attainment status for the current $O_3$ standard of 0.12 ppm (hourly maximum) in all but five Air Quality Control Regions in 1987 would range from 4 to 6 billion dollars (3). There is a need to address the deficiencies that have hampered past attempts to quantify the economic benefits of pollution control.

Research and field observation by most scientists in the U.S. indicate that $O_3$ alone or in combination with $SO_2$ and $NO_2$ is responsible for up to 90 percent of the air pollution caused crop loss in the U.S. Four publications directly address the assessment of crop losses (13, 27, 28, 29), as does the manuscript by Lokey et al. (30). Vegetation is the most sensitive biological component to air pollution stress from $O_3$, $SO_2$, and $NO_2$. Evaluation of any air quality standard should include an assessment of crop losses so that the economic impact of the standard can be understood. The current $O_3$ standard of 0.12 ppm for 1 hour does not protect crops but may be rational when comparing costs of control with benefits of control. Using data analysis from the above publication, an assessment of direct economic losses would be between $1 and $2 billion. This amounts to 2 - 4% of the crop agricultural system. It does not include forestry, natural systems, or secondary economic analysis. Thus, long term crop losses from air pollutants (especially $O_3$) may be substantial in terms of reduced agricultural production.

The National Crop Loss Assessment Network (NCLAN) was initiated by EPA to evaluate the significance of crop losses caused by air pollution. The concept was strongly supported by EPA's Office of Research and Development through recommendations from the Research Committees. A Research Management Committee (RMC), representing six air pollution research programs within the U.S., was asked to plan, manage, and execute the NCLAN plan. The project's primary objectives are:

1. to define the relationships between yields of major agricultural crops and doses of ozone ($O_3$), sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), and their mixtures, as required to satisfy the needs of the economic assessment and to support the development of National Ambient Air Quality Standards (NAAQS);

2. to assess national primary economic consequences resulting from exposure of major agricultural crops to $O_3$, $SO_2$, $NO_2$, and their mixtures; and

3. to advance the understanding of the cause and effect relationships that determine crop response to pollutant exposures.

The experimental design specifically seeks to minimize the interpretive problems of previous studies. Crops are grown in the field, at several locations around the country. Perturbation of the plant environment due to the exposure apparatus is minimized and pollutant doses are realistic, both in concentration and time series statistics. Crop yield is the dependent variable measured. The environmental and physiological variables now understood to have an effect on yield are also being measured.

A network of field sites are producing the data required for developing field validated dose-response functions. Four Regional Crop Loss Assessment Program (RCLAP) field sites, plus one regional subsite, were selected in agriculturally important areas throughout the United States (Table 1, Figure 1). Field study sites were selected to: 1) represent different climatological conditions; 2) represent different crop growing regions; and 3) make use of established research groups with a history of research on air pollutant effects on vegetation.

TABLE 1. SITE LOCATIONS, REGIONAL COORDINATORS, AND SENIOR SCIENTISTS

| | Site Location | Regional Coordinator | Senior Scientists |
|---|---|---|---|
| 1. | Northeast Regional Crop Loss Assessment Program (NERCLAP) | Leonard Weinstein<br>Boyce Thompson Institute<br>Ithaca, New York | Robert G. Amundson<br>Robert J. Kohut<br>John A. Laurence |
| 2. | Southeast Regional Crop Loss Assessment Program (SERCLAP) | Walter W. Heck, USDA<br>North Carolina State University, Raleigh, NC | Jesse H. Bennett<br>William W. Cure<br>Allen S. Heagle<br>Howard E. Heggestad |
| 3. | Central States Regional Crop Loss Assessment Program (CSRCLAP) | Joseph E. Miller<br>Argonne National Lab<br>Argonne, Illinois | Lance W. Kress |
| 4. | Southwest Regional Crop Loss Assessment Program (SWRCLAP) | O. Clifton Taylor<br>University of California<br>Riverside, California | |
| 5. | Northwest Regional Crop Loss Assessment Program (NWRCLAP) | Eric M. Preston<br>Environ. Prot. Agency<br>Corvallis, Oregon | Richard M. Adams<br>Grady Neely |
| 6. | Lawrence Livermore National Laboratory | | Gail Bingham<br>James R. Kercher |
| 7. | Brookhaven National Laboratory | | Paul D. Moskowitz |

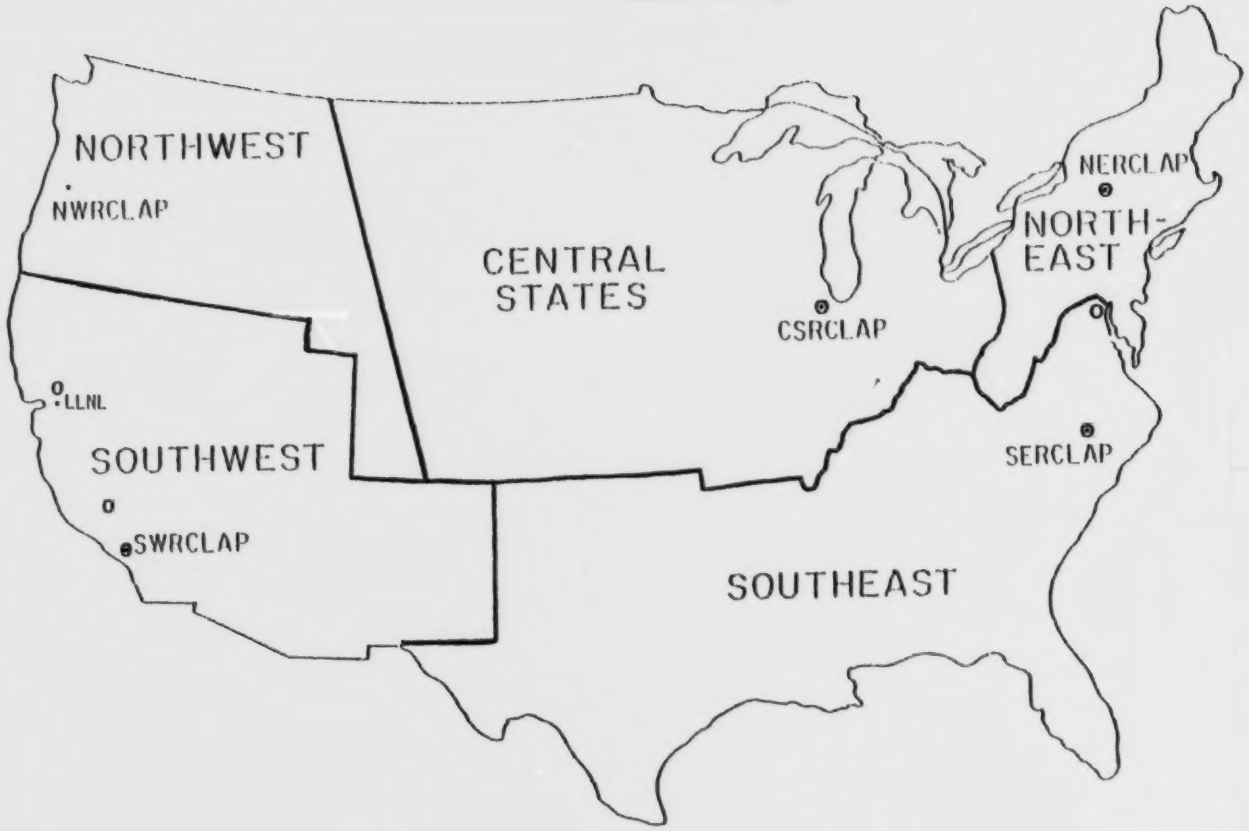


Figure 1. National Crop Loss Assessment Network, regional boundaries and location of the Regional Crop Loss Assessment Projects (RCLAP).

- • Administrative Centers
- O Field Site

Ozone and $SO_2$ were selected for initial studies because they are known to cause the most damage to vegetation. Nitrogen dioxide is included in several initial experiments and will be more intensively studied as additional support is obtained.

Three stages in the development of dose-response functions are planned. The first will involve simple empirical correlation of measured doses with observed yield. The second will incorporate the interactive effects of edaphic, climatic, and ontogenetic factors with pollutant exposure on crop yield into empirical models. The third will involve simulation of the effects of air pollution on crop growth dynamics. Because of the extensive research necessary to develop complex response functions, it is anticipated that they will not be available for more than a couple of crops (species) during the 1984 NAAQS review.

A field-oriented research approach is necessary to obtain data applicable to the assessment of actual or potential yield losses. It is difficult to determine the specific effects of a particular pollutant on crop yield under field conditions because of possible interactions with other factors affecting yield such as weather, soil conditions and fertility, pathogens and pests, and other pollutants. Therefore, isolation of the effects of specific pollutants from other factors requires some degree of experimental control, yet the conditions must not be too far from the field environment if a realistic quantification of damage is to be obtained.

Two primary pollutant exposure methods have been used to develop dose-response information considered useful in criteria documents. The first involves experimentation at varying distances from a source resulting in plant exposure to a pollution gradient. The second requires experimental manipulation of pollutant concentrations around the crop plants. The second approach has been adopted by NCLAN and is the only feasible approach when the air pollutant or group of pollutants are a regional problem and are present in ambient air in significant concentrations.

Currently, the exposure facility which permits the best control of pollutant concentrations under field conditions is the open-top chamber (Figure 2) (4, 5, 8). These chambers permit control of gas(es) around the plant canopy, allowing specific pollution regimes to be imposed on the plants in a dose-response experiment. Reports by Heagle and associates (6, 7, 9, 10) have shown that the chambers have little effect on the growth and yield of the crops they studied.

A secondary exposure facility, the Zonal Air Pollution System (ZAPS) was tested in 1980 at several locations and will be used at the CSRCLAP site at least through the 1981 season. This system was used with some success with western wheatgrass (11) and with soybeans (12). The pollutant gases are released from a series of pipes suspended over the plant canopy. Thus, it provides a response function that does not include a chamber effect. It does not provide a pollution-free control and the pollutant dose is difficult to control and characterize.

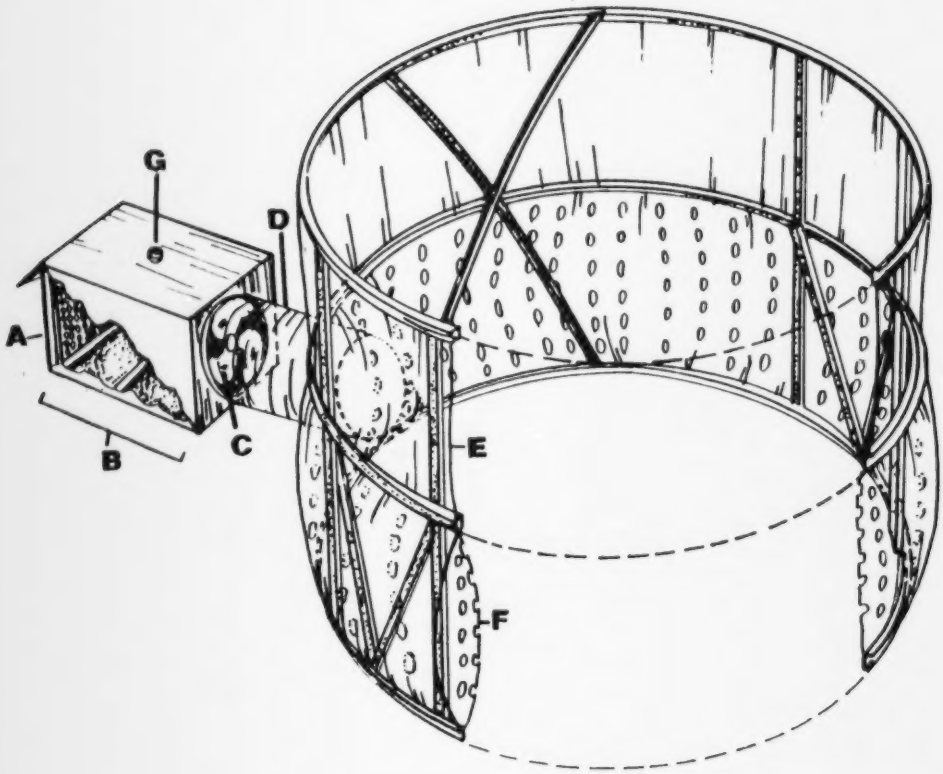


Figure 2. Schematic of the Open-Top Field Chamber (3-m diam. by 2.43 m in height). This cylindrical chamber consists of an aluminum frame covered by the clear PVC plastic film Rollaglas. A. fiberglass particulate filter B. sheet metal box; C. 0.5 hp axial blade fan D. connecting duct E. upper panel and F. perforated lower duct panel.

This report covers the research done in 1980 at the RCLAP sites. Studies utilizing similar experimental approaches are presented together. Results from the open-top chambers, the ZAPS, and special projects conducted at Riverside, California and Brookhaven National Laboratory.

## SECTION 2

## CONCLUSIONS

The first annual NCLAN report covers a number of dose-response experiments and an economic impact assessment review and update based on data from the literature.

The primary experimental design with open-top chambers used five $O_3$ concentrations and four replications with a different crop at each site (NE--red kidney bean, SE--peanut and turnip, CS--soybean, SW--head lettuce). Dose-response data were developed for each crop. Chamber effects were identified for peanut (a light effect) and turnip (a frost effect). Ambient ozone concentrations caused yield reductions in soybean (10%), peanut (14%), head lettuce (50%), and red kidney bean (2%). Statistically significant yield reduction was shown in all crops at a 7-hr/day seasonal $O_3$ average concentration (0900 - 1600 standard time) of 0.06 to 0.07 ppm.

Open-top chambers were utilized in a study at Beltsville, Maryland in which $SO_2$ incremental square wave $SO_2$ treatments were added to charcoal-filtered (low $O_3$) or nonfiltered (ambient $O_3$) ambient air in a tomato study. Ambient $O_3$ caused a 16% decrease in tomato yield. There was an additive response in tomato to added $SO_2$ in the range of 0.06 to 0.24 ppm $SO_2$ treatments (5 hr/day, 5 days/week). When added at 0.12 ppm there was a 24% yield reduction in the presence of ambient $O_3$ but only a 5% yield reduction in filtered air.

Sulfur dioxide dose-response studies using the zonal air pollution systems (ZAPS) were conducted at the CS (soybean), SE (peanut), and NE (red kidney bean) sites. Corsoy soybean showed a significant yield increase at several $SO_2$ concentrations below 0.16 ppm and yield reduction at concentrations above 0.24 ppm. Williams soybean was apparently more sensitive, showing significant yield reduction at several exposures above 0.14 ppm and no cases of yield increase. Regression analysis indicated no significant relationship between $SO_2$ dose and yield of red kidney bean. Due to drought conditions and a decision not to irrigate, only 12% of the peanut pods had nuts of marketable quality. No useable dose-response data were obtained.

The ZAPS was also used at Argonne to study the interaction of $SO_2$ and $NO_2$ on Northrup King 1492 soybean. Three ZAPS were used ($SO_2$, $NO_2$, and an $SO_2$ + $NO_2$). No effects of the individual gases were noted, but all combinations of the gas mixture caused a reduction in soybean yield. The results suggest a greater-than-additive response of the soybean to the gas mixture.

An ozone screening program was conducted at Riverside (SW) using a large number of species and cultivars. Effects were compared between a high and low ozone area. Cultivars of intermediate sensitivity were identified for 12 species.

Brookhaven National Laboratory did an initial damage assessment and data analysis using the Benedict model. Results suggest that crop damage from oxidants has increased since 1969. The work identified four areas of primary concern in an assessment effort: damage functions, air quality estimates, yield data, and economic loss translation.

## SECTION 3

## RECOMMENDATIONS

This is the first annual report of a 5-year program. Thus, the recommendations given conform to the planned program for the 2nd year.

The field research will include work with $O_3$ and $SO_2$. The research for each regional site will add to the dose-response data base, develop methodologies for physiological measurements and growth analyses in the open-top chambers, and develop the necessary data bases for the modeling and economic assessment. Specific research at all locations is overviewed.

1. NERCLAP

   -- Define the yield response of soybean ('Hodgson') to ozone; develop techniques for physiological measurements and growth analysis.

   -- Evaluate pollutant interactions on soybean ('Hodgson') using the linear gradient system with $SO_2$ and $NO_2$.

   -- Examine the interactive effects of $SO_2$ with disease and $SO_2$ with insects on crop yield.

2. SERCLAP

   -- Define the yield response of soybean ('Davis') to $O_3$ x $SO_2$ in two different soils (at Raleigh, North Carolina).

   -- Define the yield response of two soybean cultivars ('Williams' and 'Essex') to $O_3$ x $SO_2$ in a partial replicated experimental design (at Beltsville, Maryland).

3. CSRCLAP

   -- Define the yield response of corn ('PAG-397' and 'Pioneer 3780') to $O_3$ using three replications.

   -- Define the yield response of corn ('PAG-397' and 'Pioneer 3780') to $SO_2$ using the ZAPS.

   -- Screen 14 corn cultivars to ozone using the ZAPS design.

   -- Define the yield response of soybean ('NK-1492') to $SO_2$ x $NO_2$ using the ZAPS.

4. SWRCLAP

   -- Define the yield response of cotton to $O_3$ and water stress (at Shafter, California).

5. LLNL

   -- Develop automatic controllers for $O_3$ and $SO_2$.

   -- Develop data bases needed for economic assessment and modeling.

   -- Conduct modeling workshop to define the modeling approaches most appropriate to NCLAN needs.

   -- Define the yield response of tomato to $O_3 \times SO_2$.

6. NRWCLAP

   -- Conduct an economics workshop to define the most appropriate approach to NCLAN economic assessments.

7. BNL

   -- Direct EPA RTP in development of an air quality data base sensitive to the requirements of dose-response and economic modeling.

   -- Develop regionally averaged dose-response functions for specified crops.

   -- Develop data bases sensitive to modeling needs and economic assessment.

## SECTION 4

## OZONE DOSE-RESPONSE DATA: THE OPEN-TOP CHAMBERS

In ozone dose-response experiments, open-top chambers (Figure 2) were placed in the crop field in a randomized block design (Figure 3). Plants were exposed to a fixed $O_3$ addition to ambient levels. The temporal pattern in $O_3$ concentrations was determined by the variation in ambient concentrations at each site. Ozone was added during the same 7-hour period of each day (when $O_3$ concentrations are normally the highest: 0900-1600 hr Standard Time). The five $O_3$ treatments were:

1. Control (CF)--the charcoal filtered air treatment resulted in $O_3$ concentrations of 20 to 50% of ambient $O_3$ due to influx of ambient air through the open-top (in some parts of the country, this represents an approximate background concentration);

2. Ambient (NF-1)--nonfiltered treatments had sufficient $O_3$ added for 7 hr/day to compensate for system losses (about 0.015 ppm);

3. NF-2--as NF-1 with 0.03 ppm of $O_3$ added for 7 hr/day;

4. NF-3--as NF-1 with 0.06 ppm of $O_3$ added for 7 hr/day;

5. NF-4--as NF-1 with 0.09 ppm of $O_3$ added for 7 hr/day.

The chamber fans were not run between 2100 and 0500 hr (Standard Time) to allow dew formation. Exposures were not conducted on rainy days. The NF-1 chamber plots were compared with open air ambient plots (AA) to evaluate the effects of chambers on plant response.

This design was used at CSRCLAP, SERCLAP, and NERCLAP. The design employed at SWRCLAP was similar, but treatments were the result of $O_3$ removal as well as addition. This was necessary because the Riverside, California, location has high ambient $O_3$ concentrations.

### CENTRAL STATES REGIONAL CROP LOSS ASSESSMENT PROGRAM (CSRCLAP): ARGONNE NATIONAL LABORATORY (SOYBEAN)*

Soybeans are a major crop in the world and are one of the leading cash crops in the midwestern United States. Soybeans are sensitive to $O_3$ and yield reductions have been demonstrated under field conditions (13, 14, 15). Howell et al. (14), in Maryland, found the yields of soybean averaged 20% less in nonfiltered (NF) versus charcoal-filtered (CF) field chambers over a 3-year

* Lance W. Kress and Joseph E. Miller.

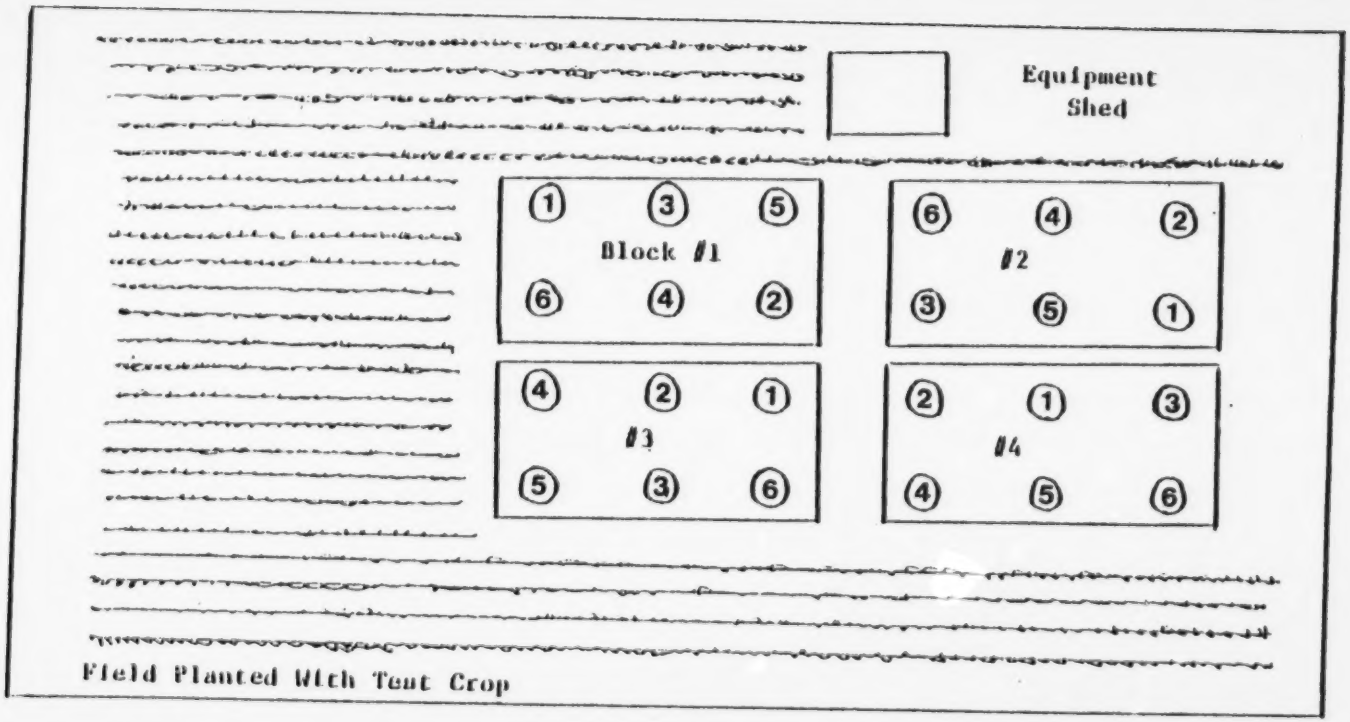


Figure 3. Schematic of a field layout for the field open-top chamber design. Field was planted and the crop established. Twenty-four plots were identified and four blocks of six plots each were chosen. Then the treatments were randomized within each block. Each of six treatments occurred in all blocks. Chambers were then placed over the appropriate 20 plots. The design shown is one possible arrangement.

period. The ozone exposed seeds from that study contained more oil and less protein than those in charcoal filtered chambers (16). In Minnesota, Kohut et al. (15) noted a 24% yield reduction for soybeans grown in field chambers with NF air compared to CF air. Heagle et al. (13), in North Carolina, in the only field generated dose-response study, reported soybean yield reductions of 6, 14, 22, and 30% associated with seasonal 7-hr/day mean $O_3$ concentrations of 0.07, 0.08, 0.09, and 0.10 ppm, respectively.

## Materials and Methods

This research was conducted approximately 25 miles southwest of Chicago, Illinois. A 60 m x 90 m plot that had been in turf for several years was plowed, fertilized as per soil test recommendations (600 lbs/acre, 9-23-30), and disced. The plot was further prepared by hand tilling with a rototiller prior to planting.

Rhizobium inoculated soybeans [Glycine max. (L.) Merr. 'Corsoy'] were planted on 24 June 1980 with a 1-m row spacing at a density of approximately one seed per 2.5 cm. The experimental plots (two 2.9-m rows/plot) were later thinned to a 5 cm spacing. The plots were hand weeded as necessary. Irrigation was not needed. Insect and fungal infestations were minimal, but a virus problem (Southern Bean Mosaic and Tobacco Ring Spot) became manifest in September. Virus infected plants were mostly stunted, remained green while the rest of the plants senesced in the fall, and produced few or no seeds. The percentage of virus affected plants in the experimental plots varied from 20-32%.

A randomized block design incorporating four replicates of six treatments was used. The treatments were AA, no chamber; CF, charcoal-filtered air chamber; NF-1, unfiltered air ($O_3$ concentration equal to that in ambient air); NF-2, NF-3, and NF-4, unfiltered air plus 0.03, 0.06, and 0.09 ppm $O_3$ above ambient, respectively. Ozone was added to the chambers from 0900 - 1600 CST daily. Ozone was not added on rainy days, thus the actual $O_3$ concentration averages were somewhat less than 0.03, 0.06, and 0.09 ppm above ambient in those respective treatments. The open-top chambers (6, 8) were not established over the experimental plots until August 4, and the $O_3$ exposures began on August 6. Ozone exposures were terminated and the plastic was removed from the chambers on October 9, 1980. Out of 65 possible exposure days, 3 full days and 7 half days were not utilized due to rain.

Ozone was generated by silent electric discharge with an OREC model 03B2-0 $O_3$ generator. Ozone measurement was performed with Bendix model 8002 chemiluminescent $O_3$ monitors calibrated with a Dasibi model 1008-PC $O_3$ photometer. The July $O_3$ data were obtained with a Dasibi model 1003-AH analyzer at the Atmospheric Physics building approximately 1,000 meters from the experimental plot. Rainfall, wind speed, and wind direction were also collected at the Atmospheric Physics building.

The plants were harvested in mid-October following leaf abscission. Four 50-cm soybean samples were collected in each row. The 45-cm on each row adjacent to the chamber wall was discarded. Only the pods were harvested, but the number of plants, number of virus affected plants, and number of pods (if

any) from virus affected plants per 50-cm row segment were recorded. Other parameters measured were foliar injury (on August 22, September 22, and October 2), total number of pods, unfilled pods, seeds, and seed weight after drying at 64°C for 48 hours. Values for seeds/plant, seed weight/plant, and weight per seed were calculated. Ninety-six seed samples (four from each plot) were sent to the University of Illinois for oil and protein analysis. Due to the potential impact of the virus affected plants on the yield per plant parameters, all the values (measured and calculated) were adjusted as necessary to remove the effects of the virus affected plants. The number of plants was adjusted by subtracting the number of stunted plants, pods were adjusted by subtracting the number of pods from stunted plants, seeds were adjusted by subtracting 1.25 x number of pods from stunted plants (approximately three-fourths of the pods from stunted plants had only one seed), and seed weight was adjusted by subtracting the percentage of seed from stunted plants x the total seed weight.

An analysis of variance was performed on the yield data by the Statistical Analysis System (SAS). Duncan's Multiple Range Test was utilized to test for mean differences at $P = 0.05$. A general linear regression model (GLM) was performed by SAS to generate the regression equations.

## Results

The ambient air $O_3$ data collected during the pertinent part of the 1980 growing season (July, August, and September) are summarized as daily 7-hr (0900 - 1600 CST) and 24-hr means (Figure 4). The highest and second highest hourly $O_3$ concentrations occurred on July 19; 0.205 ppm for 1400 - 1500 and 0.210 ppm for 1500 - 1600. The highest 7-hr (0.169, 1300 - 2000 CST) and 24-hr (0.086 ppm) averages also occurred on July 19.

The seasonal 7-hr/day average $O_3$ concentration curves for the six experimental treatments are presented in Figure 5 for the experimental exposure period.

During the August evaluation of foliar injury, oxidant symptoms were noted only for the NF-3 and NF-4 treatments. By the September evaluation some leaves were beginning to senesce.

The ANOVA test, using plot averages for the various yield parameters, indicated significant treatment effects for all parameters except percent oil content (Table 2). A significant block effect was indicated only for weight per seed.

The yield data demonstrate that as the $O_3$ concentration increased, seed number and weight decreased (Table 3, Figure 6). There were no significant differences between the AA plot and the NF-1 plot. Between the CF and NF-1 plot only weight per seed was significantly reduced. The significant decline in total seed weight between the NF-2 (0.064 ppm) and NF-3 (0.089 ppm) and between the NF-3 and NF-4 (0.115 ppm) plots was matched by declines in seed number and weight/seed. Thus, as $O_3$ increased there were fewer seeds produced and they were smaller. The $O_3$ treatments had a significant effect on the oil and protein content of the seed only in the highest $O_3$ treatment.

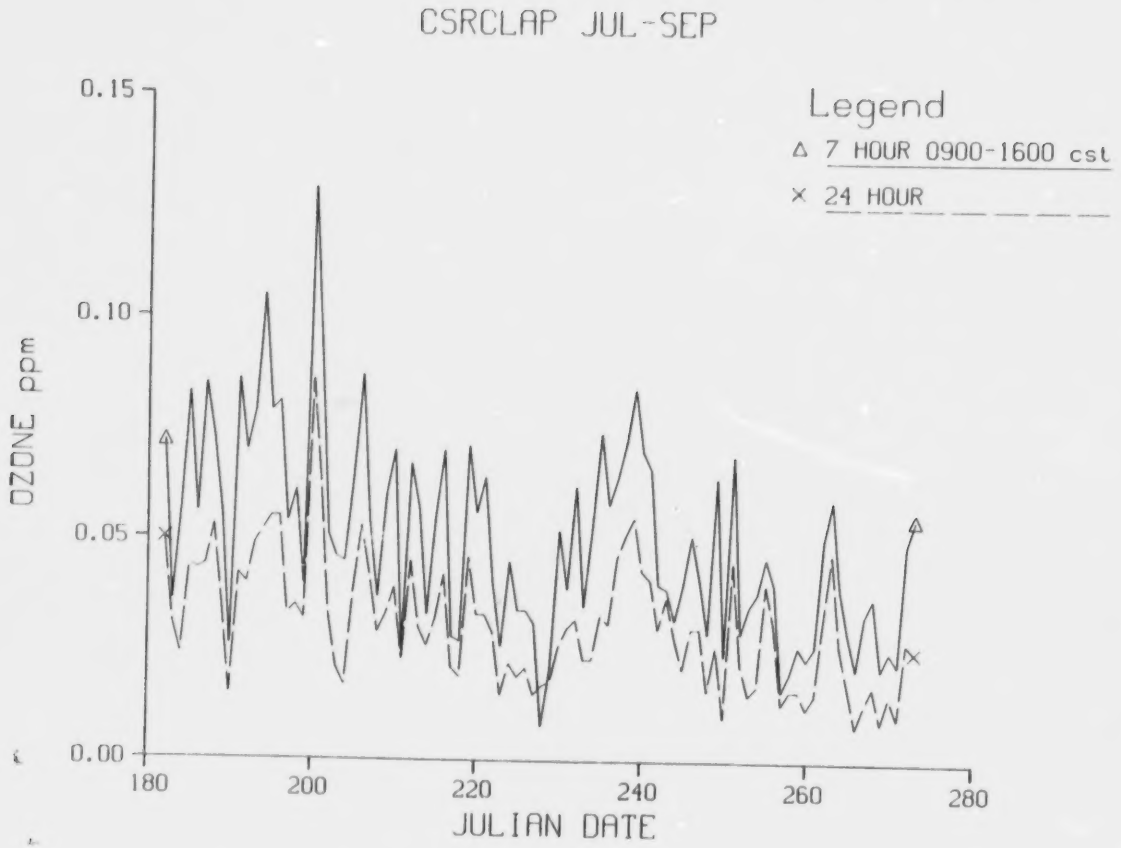


Figure 4. Ambient $O_3$ data collected from July 1 (182) through September 30 (273), 1980, showing daily 7-hr ave and daily 24-hr ave. Experimental treatments began on August 6 (218).

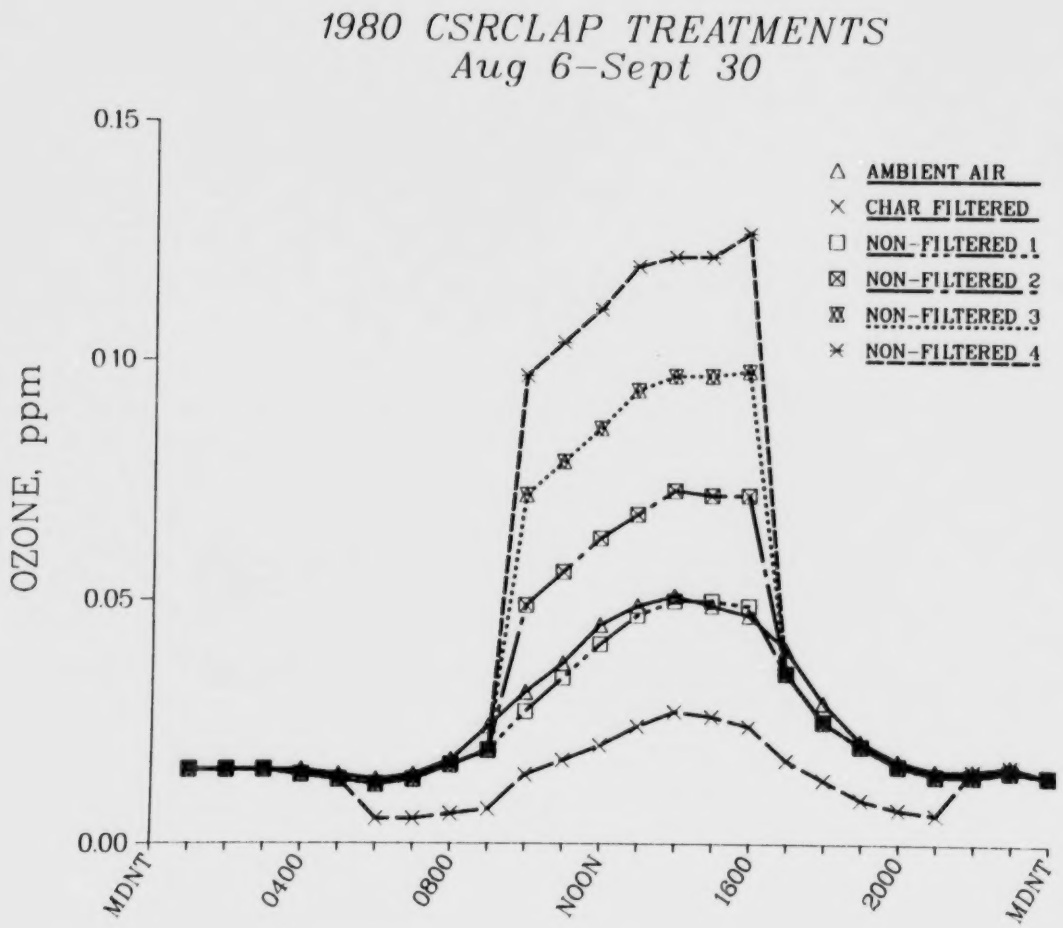


Figure 5. Mean $O_3$ concentrations in ambient air (AA), charcoal-filtered air chambers (CF), or in nonfiltered chambers with various concentrations of $O_3$ added for 7-hr/day (0900 - 1600 CST) during the actual exposure period of the experimental plants. All chamber fans were turned off nightly from 2130 - 0530 CST.

TABLE 2. RESULTS OF THE ANOVA TEST TO DETERMINE SIGNIFICANCE OF TREATMENT AND BLOCK EFFECTS RESULTING FROM EXPOSURE OF SOYBEANS TO SEASONAL 7-HR/DAY MEAN $O_3$ CONCENTRATIONS OF 0.022, 0.042, 0.064, 0.089, AND 0.115 PPM FOR 65 DAYS DURING THE 1980 SEASON

| | | Mean Square† | | | | | |
|---|---|---|---|---|---|---|---|
| Source | df | Number of Seeds | SW (g) | SW/P (G) | SW/HP (g) | W/S (g) | % Oil | % Protein |
| Treatment | 5 | 40469** | 1755** | 34.15** | 76.95** | 0.00066** | 0.7887 | 2.613* |
| Block | 3 | 6307 | 280 | 5.23 | 5.23 | 0.00008* | 0.2524 | 1.0233 |
| Error | 15 | 6561 | 152 | 2.33 | 2.34 | 0.00002 | 0.2965 | 0.8230 |

† Significance values: * = $P < 0.05$; ** = $P < 0.01$.

SW = Seed Weight
SW/P = Seed Weight/Plant
SW/HP = Seed Weight/Healthy Plant
W/S = Weight/Seed

TABLE 3. YIELD PARAMETERS OF SOYBEAN EXPOSED TO 7-HR/DAY $O_3$ TREATMENTS DURING THE 1980 SEASON

| Ozone Treatment | Ozone (ppm)‡ 7/1-9/30 | Ozone (ppm)‡ 8/6-9/30 | Yield per 50 cm† Row Segment: Number of Seeds | SW (g)# | SW/P (g)# | SW/HP (g)# | W/S (g)# | % Oil | % Protein |
|---|---|---|---|---|---|---|---|---|---|
| CF | 0.037 | 0.022 | 718 ab* | 108 a | 13.9 ab | 20.4 a | 0.149 a | 19.5 a | 38.9 b |
| AA | 0.050 | 0.042 | 742 ab | 105 a | 13.8 ab | 19.0 a | 0.141 b | 19.2 a | 38.9 b |
| NF-1 | 0.050 | 0.042 | 784 a | 112 a | 14.1 a | 18.4 a | 0.143 b | 19.2 a | 38.3 b |
| NF-2 | 0.064 | 0.064 | 694 ab | 95 ab | 11.5 bc | 14.9 b | 0.137 b | 18.9 ab | 39.6 ab |
| NF-3 | 0.079 | 0.089 | 612 bc | 77 bc | 9.4 c | 11.7 c | 0.125 c | 19.0 ab | 39.5 ab |
| NF-4 | 0.094 | 0.115 | 508 c | 58 c | 7.0 d | 9.4 d | 0.115 d | 18.2 b | 40.7 a |
| | | | Yield Expressed as a Percent of CF Plot | | | | | | |
| AA | | | 103 | 97 | 99 | 93 | 95 | 98 | 100 |
| NF-1 | | | 109 | 104 | 101 | 90 | 96 | 98 | 98 |
| NF-2 | | | 97 | 88 | 83 | 73 | 92 | 97 | 102 |
| NF-3 | | | 85 | 71 | 68 | 57 | 84 | 97 | 102 |
| NF-4 | | | 71 | 54 | 50 | 46 | 77 | 93 | 105 |

† Yield values were adjusted to remove effects of virus affected plants. Seeds = total seeds - seeds from virus affected plants. Seed weight = total seed weight - weight of seed from virus affected plants.

‡ Seasonal 7-hr/day average $O_3$ concentration, 0900 - 1600 CST. Full growing season = 7/1 - 9/30. Experimental treatment period = 8/6 - 9/30.

* Values in a column followed by the same letter are not significantly different at $P < 0.05$.

# SW = seed weight, SW/P = seed weight per plant, SW/HP = seed weight per healthy plant, W/S = weight per seed.

Regression equations for the five chambered treatments are presented for seed weight per healthy plant and weight per seed in Figure 6. A linear regression equation appeared to be the best description of the curves, with a correlation coefficient of 0.93 for each curve.

To determine if there were any position within chamber effects, an ANOVA was performed utilizing the eight samples per plot (192 total data points). The test results indicated no significant position within plot effects or position by treatment interactions.

## Discussion

The $O_3$ concentrations used in this experiment had a significant impact on the yield of soybeans. As $O_3$ increased there were fewer, smaller seeds with a lower oil content. The addition of 0.022 ppm $O_3$ (NF-2) above ambient caused a significant reduction in seed weight per plant. The yield reduction values generated in this experiment appear to be very comparable with experimental results collected from soybean in North Carolina over the past 3 years [Heagle, pers. comm.; Heagle et al. (13)].

A comparison of the AA plots with the NF-1 plots revealed no significant chamber effect for any of the measured parameters.

In the present study both percentage oil and protein were not significantly different between the NF-1 plots and the CF plots. Although the protein content of the NF-4 seeds was significantly increased (7%) over the NF-1 seeds, the seed yield reductions would lead to less actual protein yield at the elevated $O_3$ concentrations. The decreased oil content at elevated $O_3$ concentrations would only magnify the oil loss due to seed number and seed weight reductions.

## SOUTHEAST REGIONAL CROP LOSS ASSESSMENT PROGRAM (SERCLAP)--NORTH CAROLINA STATE UNIVERSITY (PEANUTS)*

Peanuts are an important crop in the south and southeast with an annual production value of 0.7 to 1.0 billion dollars. There are no data available for effects of $O_3$ on yield of peanuts. The objective here was to determine the effects of chronic doses of $O_3$ on injury, growth, and yield of peanuts in open-top field chambers.

## Materials and Methods

Seeds of peanut, Arachis hypogea L. 'NC-6' were sown in rows spaced 1 m apart with a commecial planter in a field of sandy loam soil (Appling, Typic Hapludults) on May 22, 1980. On June 3, six plots (3 $m^2$) were selected for each of four blocks on the basis of uniform plant appearance and uniformity of topsoil depth within each block. Plants were thinned on June 4 to a stand of one plant per 20 cm of row; occasional transplanting was necessary to achieve a uniform stand. A thin layer of wheat straw was placed around the peanuts on June 14 to prevent soil compaction from irrigation.

* A. S. Heagle, R. B. Philbeck, and C. A. Mitchell.

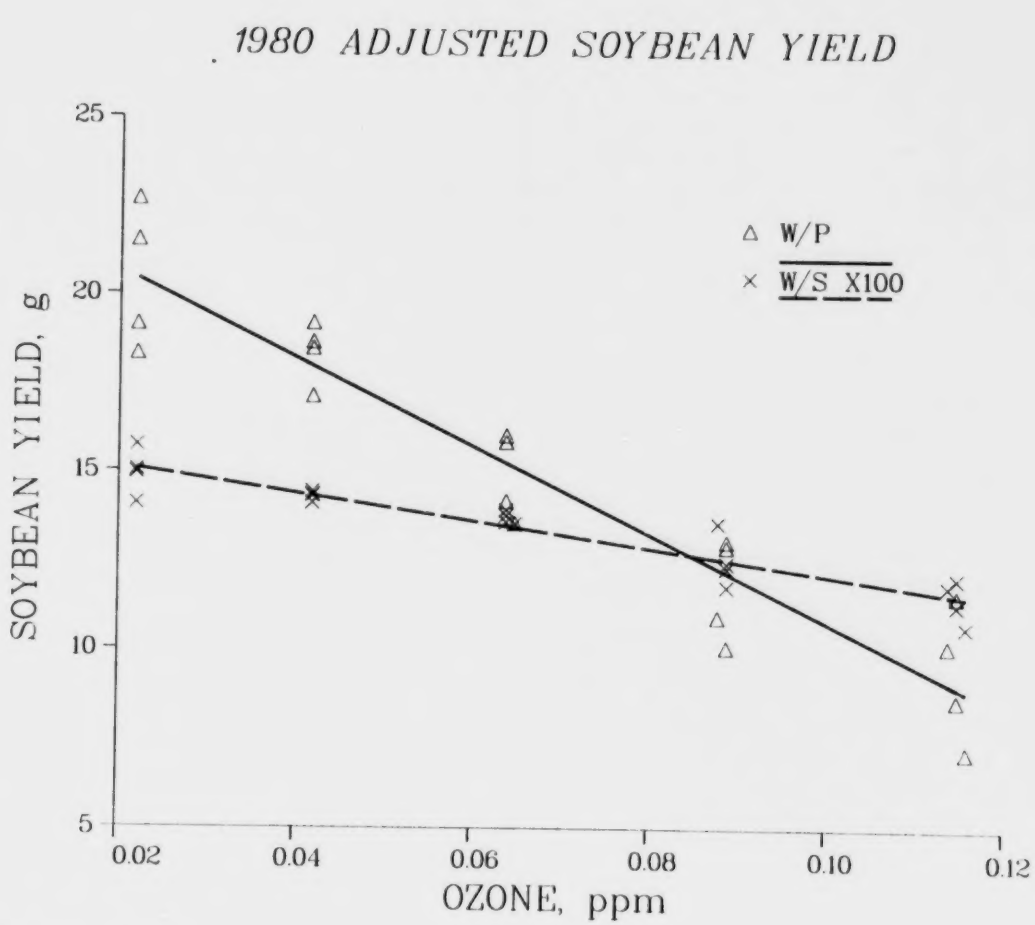


Figure 6. Dose-respone curves for soybean yield as a function of the seasonal 7-hr/day average $O_3$ concentration (August 6 to September 30). W/P = seed weight per healthy plant. W/S x 100 = weight per seed times 100, x = seasonal 7 hr/day average $O_3$ concentration. Regression equations: W/P: $Y = 23.14 + (-123.20\ x)$, $R^2 = 0.93$; W/S: $Y = 0.1591 + (-0.3791\ x)$, $R^2 = 0.93$.

On June 18, two irrometers were installed at depths of 20 and 40 cm in each plot to provide readings of soil moisture tension which were recorded three times each week. Plants in an entire block were irrigated with a hand held "rain" nozzle when irrometer readings for any plot within the block exceeded 60% of scale (0% = wet, 100% = dry). The amount of water applied for each plot was directly related to the irrometer reading (> 60% of scale = 8.7 cm; 35-60% of scale = 6.8 cm; < 35% of scale = 4.8 cm). The dates and rate of irrigation for each plot are available upon request. Plots were weeded by hand as required. Insects and mites were controlled with three applications of Carbaryl (1 tbsp 50 wp/gal) and two applications of Cyhexatin (1 g/gal).

Treatments were randomly assigned to each plot on June 10. Dispensing of $O_3$ began on June 16 and continued through October 6. Rain precluded dispensing for 7-hr periods on June 18, 25 and 26, and on September 29 and 30. Rain precluded dispensing for 3.5-hr periods on October 1 and August 17 and 22. The ozonizer malfunctioned on July 13 and 14 (7 hr each) and on July 15 and 16 (3.5-hr each).

Foliar injury was estimated on four dates at 2-week intervals beginning on July 16, 30 days after exposures began. Foliar injury was estimated as the percentage chlorosis and necrosis in 5% increments (0-100%) on individual quadrifoliate leaves on one main branch of four plants (one per quadrant) in each plot. Abscised leaves were rated as 100% injured. Leaves on the same branch were rated for injury on each date.

Sixteen plants (eight from each of two rows per plot) were tagged for treatment and chamber position and harvested on October 7. Plants were dug with a broad-tined fork and the soil was washed from the roots and pods with water. The fresh weights of shoots, roots, and pods per plant (> 1 cm long) were recorded at harvest. Pods were air-dried (to a seed moisture content of 7.5%) in coarse-mesh fresh fruit bags in a greenhouse for 15 days. Marketable pods containing seeds were then counted and weighed.

Pod samples from each treatment and block were graded for quality according to standard marketing procedures. Analyses of variance were performed on injury, growth, and yield data and LSD's were determined.

## Results

The ambient air $O_3$ data collected during the 1980 growing season (May - October) are summarized as daily 7-hr (0900 - 1600 EST) and 24-hr means (Figure 7). The seasonal 7-hr/day average $O_3$ concentration curves for the six experimental treatments are presented in Figure 8 for the exposure period during the peanut growth.

The first foliar injury appeared 3 days after dispensing began as chlorosis of the oldest quadrifoliate leaves in the NF-3 and NF-4 treatments. Injury was visible in the NF-1 and NF-2 treatments within 14 days. Foliar injury was progressive; increased exposure time resulted in increased chlorosis and necrosis which was more severe at high than at low $O_3$ levels and more severe on older than on younger leaves. Chlorosis and necrosis led to leaf abscission (100% injured) which accounted for most of the injury rating

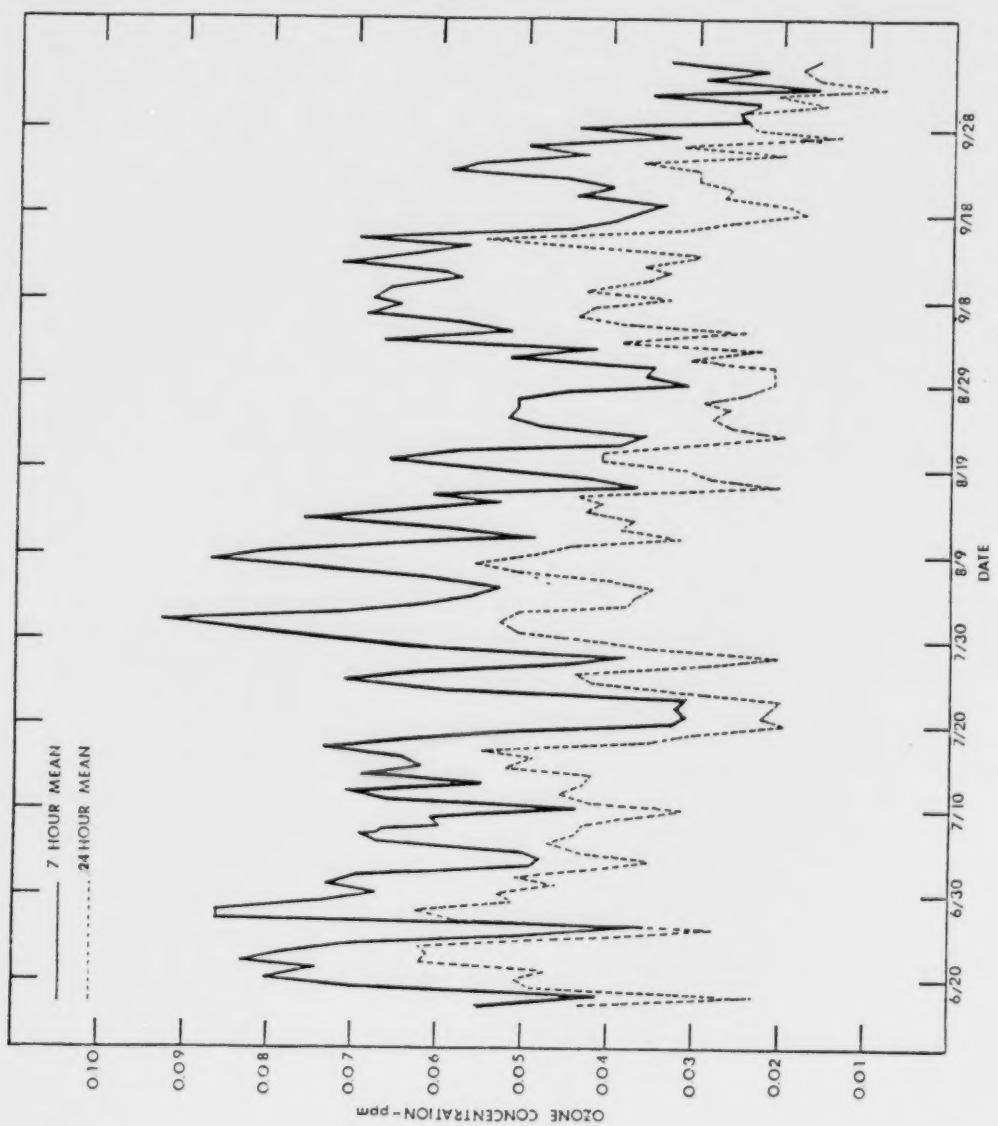


Figure 7. Ambient $O_3$ data from May - October, 1980, showing daily 7-hr average and daily 24-hr average.

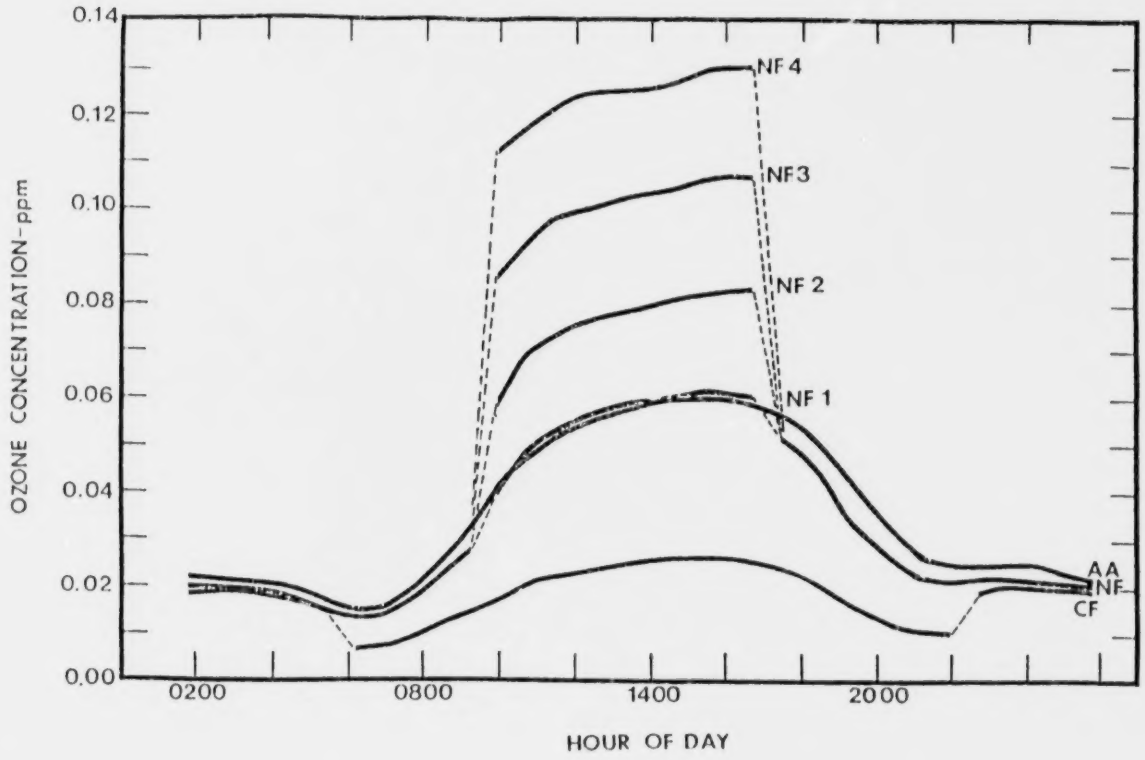


Figure 8. Mean $O_3$ concentration in ambient air (AA), charcoal-filtered air chambers (CF), or in non-filtered chambers with various concentrations of $O_3$ added for 7-hr/day (0900 - 1600 EST) during the exposure period of the experimental plants.

in the NF-2, NF-3, and NF-4 treatments. Differences between foliar injury were usually significant for all chamber treatments for all measurement dates (Figure 9). Each increment in $O_3$ caused a significant increase in foliar injury.

Mean squares from the analysis of variance for growth and yield showed that the $O_3$ treatment effect was significant for all measurements with no significant interactions (Table 4). The results were similar in all blocks. The magnitude of the $O_3$ effect was similar for all measurements but there was evidence that shoot weight was decreased more by $O_3$ than marketable pod weight or number (Table 5, Figures 10 and 11).

## Discussion

Peanut plants in the AA plots yielded better than those in the CF treatment and NF-1 treatment at a similar $O_3$ dose, indicating a chamber effect. Light differences caused by the chamber panels may be involved; light decrease in open-top chambers is greatest nearest the ground. Peanuts, which do not attain heights greater than 30 cm, would likely be affected more by light than would taller crops.

## SOUTHEAST REGIONAL CROP LOSS ASSESSMENT PROGRAM (SERCLAP)--NORTH CAROLINA STATE UNIVERSITY (TURNIP)*

Relatively little is known of the effects of chronic doses of $O_3$ on growth and yield of root crops. There are no reports for root crops exposed to different levels of $O_3$ in the field. Ozone dose-growth response information exists for turnips under controlled conditions (John Dunning, personal communication) but does not exist for turnips in the field.

## Materials and Methods

Twenty-four, 3-m diameter pots (six in each of four blocks) were cultivated by hand on October 7, 1980, with a broad-tined fork. A granular fertilizer (10-10-10, N-P-K) was broadcast at the rate of 230 g per plot and raked lightly into the soil. Four cultivars of turnips (Brassica rapa L.) 'Just Right,' 'Purple Top White Globe,' 'Tokyo Cross,' and 'Shogoin' were planted in rows spaced 60 cm in each plot on October 10. Rows were parallel to the line between the chamber door (south) and fan box (north). The cultivar row assignments (one per cultivar) were the same within blocks but different across blocks; each cultivar occupied a different row in each block.

Plants were irrigated lightly at planting with a hand-held "rain" nozzle. All cultivars emerged within 6 days after planting. Two irrometers were placed in each plot (20 and 40 cm deep) to indicate soil moisture tension. Irrometer readings, taken three times weekly, never exceeded 60% of scale and further irrigation was not necessary. Plants were thinned to clusters of three uniform plants per 15 cm of row on October 20 and to one uniform plant per 15 cm of row on November 10. Weeds were controlled by hand; no pesticide

* A. S. Heagle, R. B. Philbeck, and C. A. Mitchell.

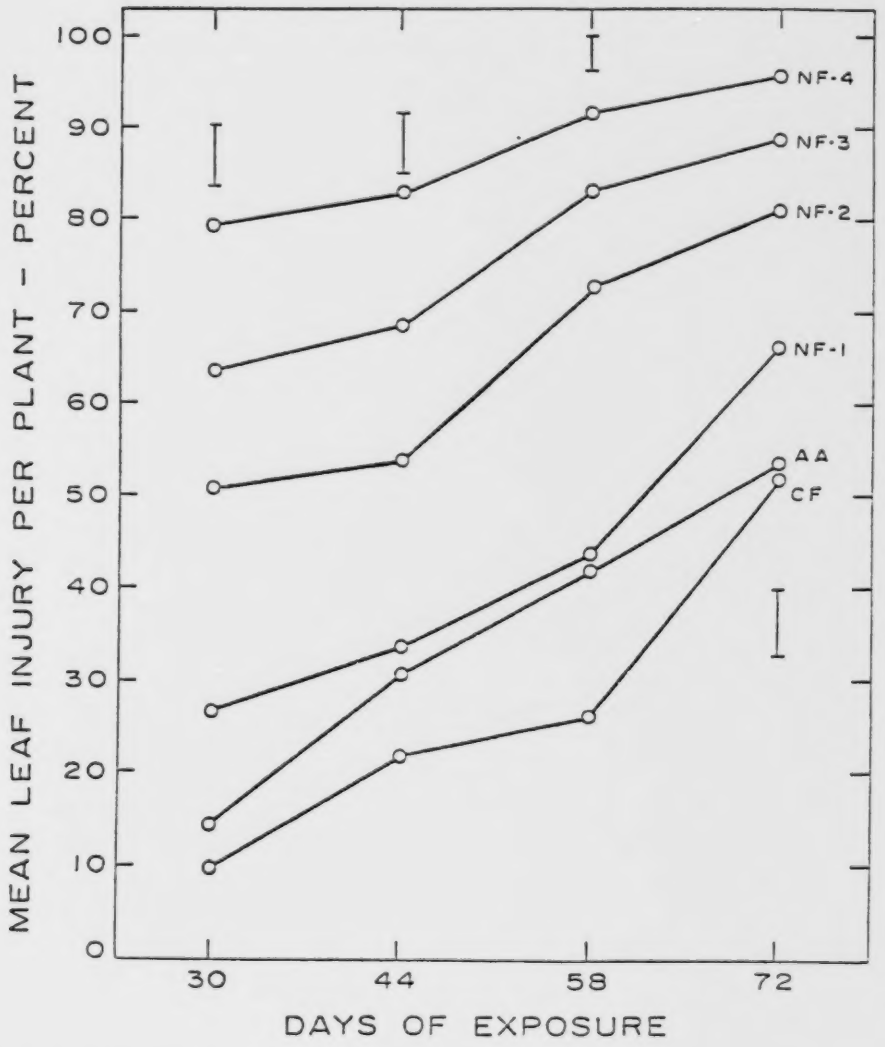


Figure 9. Mean foliar injury per leaf of peanut plants exposed in the open to ambient conditions (AA), or in open-top field chambers receiving charcoal filtered air (CF) or nonfiltered air with $O_3$ added for 7 hr/day to produce concentrations equal to ambient (NF-1) or 0.020, 0.045, and 0.069 ppm of $O_3$ above ambient (NF-2, NF-3, and NF-4, respectively.

TABLE 4. MEAN SQUARES FROM THE ANALYSES OF VARIANCE FOR GROWTH AND YIELD OF PEANUTS EXPOSED TO CHRONIC LEVELS OF $O_3$

| Source | DF | Shoot Fresh Weight (thousands) | Root Fresh Weight | Total Pod Fresh Weight (Hundreds) | Marketable Pod Weight (Hundreds) | Marketable Pod Number (Tens) |
|---|---|---|---|---|---|---|
| Block (B) | 3 | 90 | 89 | 82 | 15 | 56 |
| Treatment (T) | 5 | 6027** | 2533** | 2520** | 1300** | 2947** |
| Error A | 15 | 100 | 39 | 39 | 7 | 29 |
| Position (P) | 15 | 70 | 16 | 30 | 17 | 43 |
| T x P | 75 | 46 | 21 | 27 | 14 | 37 |
| Error B | 269 | 48 | 20 | 23 | 13 | 28 |

** $P < 0.01$.

TABLE 5. EFFECT OF $O_3$ TREATMENT ON GROWTH AND YIELD OF PEANUTS, 1980

| Ozone Treatment | Seasonal† 7 hr/day $O_3$ conc. (ppm) | Growth or Yield Measure Per Plant: Shoot Fresh Weight (g) | Root Fresh Weight (g) | Total Pod Weight (g) | Marketable Pod Weight (g) | Marketable Pod (number) |
|---|---|---|---|---|---|---|
| AA | 0.056 | 893 | 20 | 204 | 158 | 77 |
| CF | 0.025 | 1008 | 21 | 187 | 142 | 70 |
| NF-1 | 0.056 | 761 | 16 | 145 | 122 | 58 |
| NF-2 | 0.076 | 483 | 12 | 110 | 92 | 45 |
| NF-3 | 0.101 | 402 | 9 | 77 | 69 | 34 |
| NF-4 | 0.125 | 219 | 5 | 43 | 40 | 22 |
| LSD (P = 0.05) | | 119 | 2 | 24 | 10 | 6.4 |

* Each value is the mean for 64 plants (16 plants in four blocks).
† Means from June 17 through October 6, 1980 (0900 to 1400 hours EST).

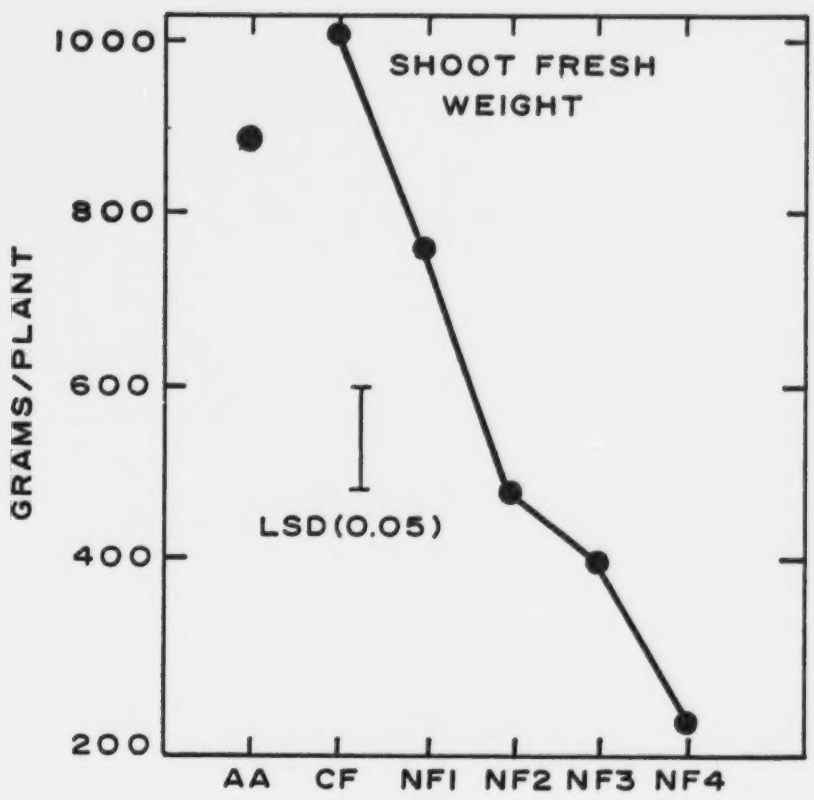


Figure 10. Shoot fresh weight at harvest for peanut plants exposed in the open to ambient conditions (AA), or in open-top chambers receiving charcoal filtered air (CF) or nonfiltered air with different amounts of $O_3$ added for 7 hr/day (NF-1, 2, 3, 4). Seasonal 7-hr/day average $O_3$ concentrations are shown in Table 5.

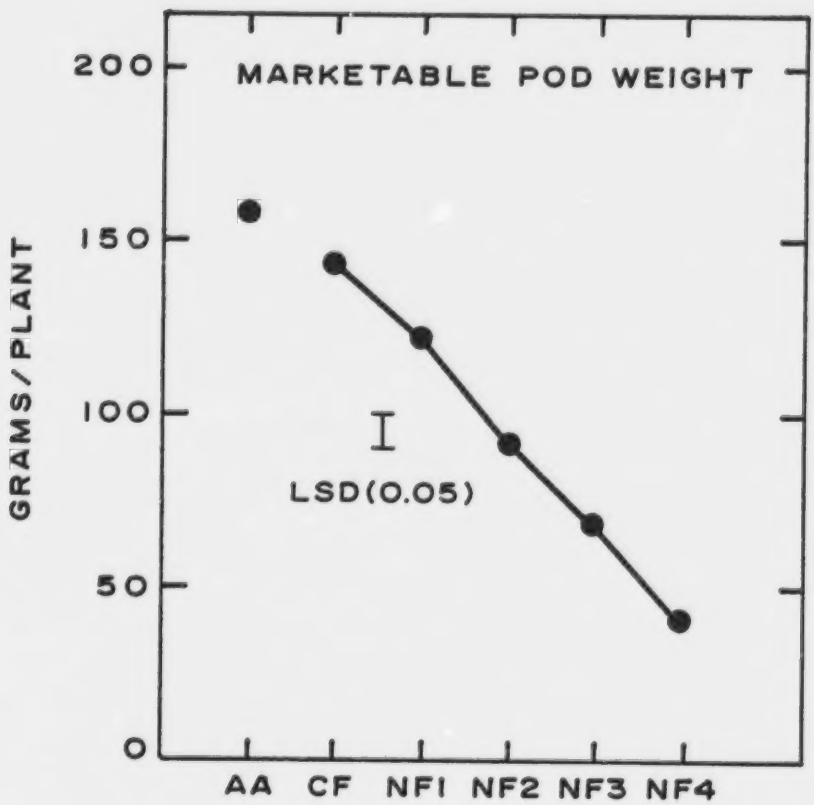


Figure 11. Marketable pod weight of peanut at harvest for plants exposed in the open to ambient conditions (AA), or in open-top chambers receiving charcoal filtered air (CF) or nonfiltered air with different amounts of $O_3$ added for 7 hr/day (NF-1, 2, 3, 4). Seasonal 7-hr/day average $O_3$ concentrations are shown in Table 5. Several regression models were tested on the open-top chambers data. The linear model ($Y = 173.20 - 1045.6\ X$; Y = yield of marketable pod in grams, X = $O_3$ concentration in ppm) was significant but the plateau-linear model was significantly better ($Y = 142.28$ if $X \leq 0.0365$, $Y = 184.62 - 1160X$ if $X > 0.0365$).

applications were required. Five chamber treatments were randomized within each block. A nonchambered plot (AA) in each block remained the same as for the peanut study.

Ozone additions began on October 20 and continued daily through November 30. Rain precluded dispensing for 7-hour periods on October 25 and 30 and on November 15, 16, 17, and 24. Rain precluded dispensing for 3.5 hour periods on Novmeber 4 (p.m.) and November 18 (a.m.).

Eight plants of each cultivar were harvested on December 1 and 2. Plants within 75 cm of the chamber edge were not included. Plants were washed; shoots and roots separated at the cotyledonary node, towel-dried, and weighed immediately. Roots and shoots for plants in one block were oven-dried (75°C for 4 days) and weighed to obtain correlations between fresh and dry weight measures. Foliar injury (chlorosis and necrosis) was visually estimated for three plants per cultivar in each plot at harvest. Injury was estimated for individual leaves (> 3 cm long) in 5% increments (0-100%). Injury and growth data were analyzed according to analyses of variance and LSD values were obtained.

Results

The ambient air $O_3$ data collected during the fall (1980) growing season (October - November) are summarized as daily 7-hr (0900 - 1600 EST) and 24-hr means (Figure 12). The seasonal 7-hr/day average $O_3$ concentration curves for the six experimental treatments are presented in Figure 13 for the exposure period during the turnip growth.

Injury was slow to develop during the first 3 weeks of exposure. Chlorosis was first noticed on cotyledons on October 30 in the NF-3 and NF-4 treatments. This symptom gradually spread to a few of the oldest leaves by November 14, but the overall degree of injury was less than 10%. The days of November 15, 16, and 17 were cold, dark, and rainy. Drizzle on the morning of November 18 also prevented dispensing of $O_3$, but the sky cleared during the morning allowing dispensing to begin at 1230 hours EST. Within 3 hours, severe watersoaking symptoms were evident on all cultivars in all plots for the NF-3 and NF-4 treatments. Two $O_3$ analyzers showed that the maximum $O_3$ levels for November 18 were 0.09 and 0.11 ppm for the NF-3 and NF-4 treatments, respectively. The water soaking symptom turned to white bifacial necrosis within 2 days. Plants in the NF-2 treatment (0.06 ppm) were also injured by the 3.5 hr exposure on November 18. Subsequent exposures did not produce additional water soaking symptoms. Probably about 80% of the foliar injury estimated at harvest was due to the November 18 exposure.

The $O_3$ and cultivar effects were significant and there was a significant $O_3$ x cultivar interaction. Differences in foliar injury between the AA and CF or NF-1 treatments were especially evident for "Shogoin" (Table 6). Evidently, Shogoin was more sensitive to frost injury caused by low temperatures than were other cultivars. No frost injury was noted in any of the chamber treatments. For the chamber treatments, "Tokyo Cross" was injured more than

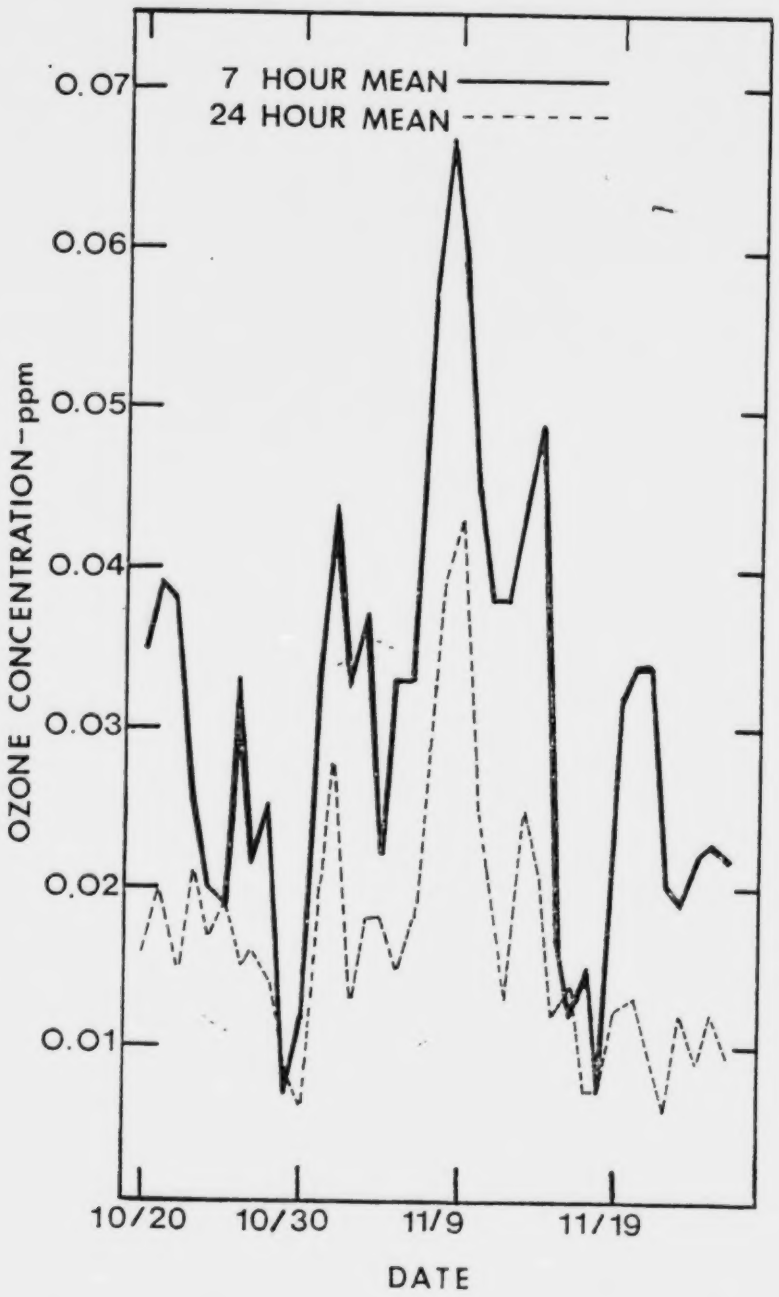


Figure 12. Ambient $O_3$ data from October and November, 1980, showing daily 7-hr average and daily 24-hr average.

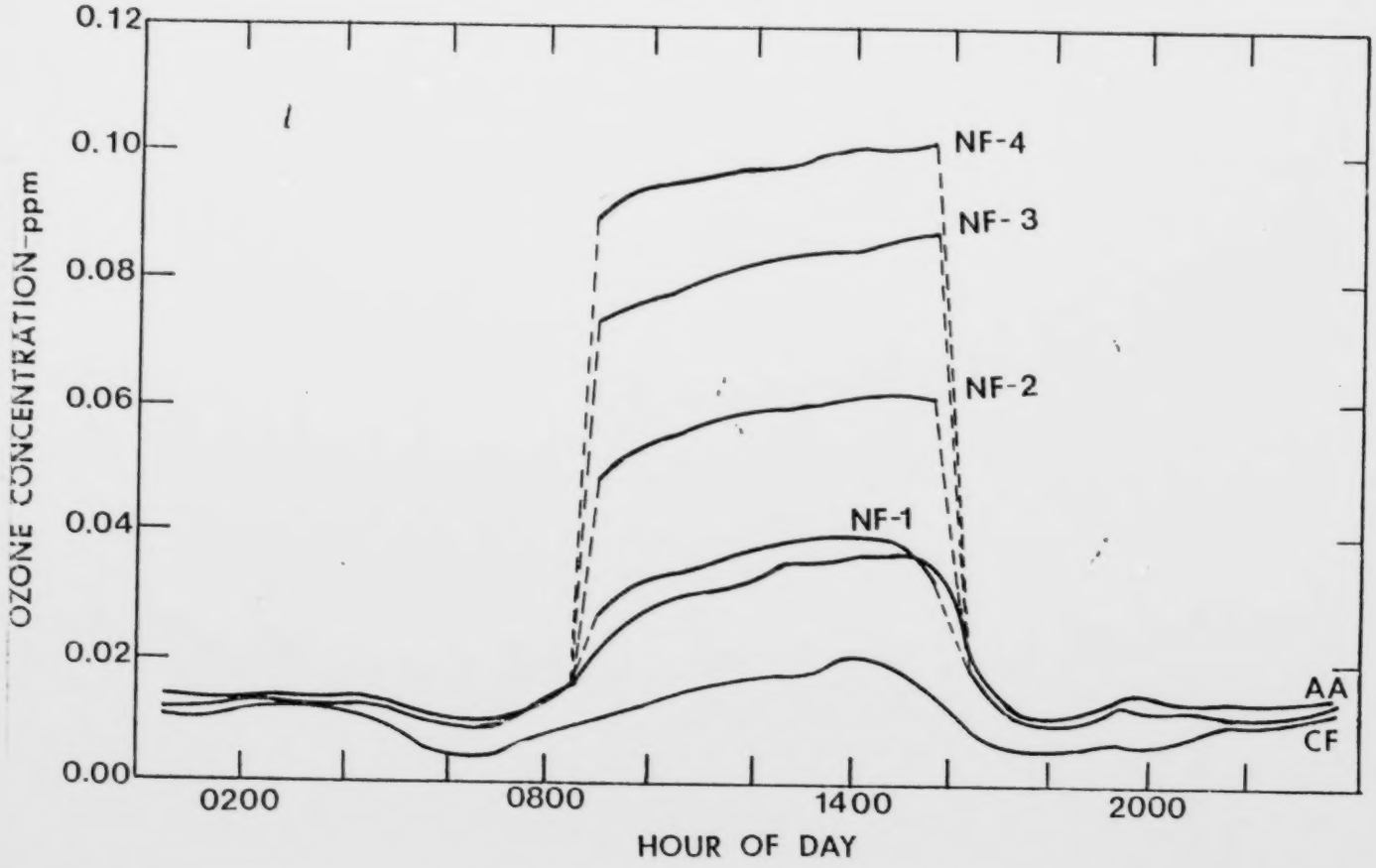


Figure 13. Mean $O_3$ concentration in ambient air (AA), charcoal filtered air chambers (CF), or in non-filtered chambers with various concentrations of $O_3$ added for 7 hr/day (0900 - 1600 EST) during the exposure period of the experimental plants.

TABLE 6. EFFECT OF $O_3$ EXPOSURE ON FOLIAR INJURY OF FOUR TURNIP CULTIVARS

| Ozone Treatment | Seasonal Mean 7 hr/day $O_3$ Conc. ppm† | Mean foliar injury per leaf per cultivar* | | | |
|---|---|---|---|---|---|
| | | Just Right | Purple Top White Globe | Tokyo Cross | Shogoin |
| AA | 0.031 | 4 | 4 | 14 | 14 |
| CF | 0.014 | 3 | 1 | 10 | 3 |
| NF-1 | 0.034 | 4 | 2 | 10 | 3 |
| NF-2 | 0.056 | 5 | 7 | 11 | 7 |
| NF-3 | 0.081 | 24 | 16 | 28 | 20 |
| NF-4 | 0.096 | 33 | 29 | 32 | 25 |

LSD (P = 0.05) Treatment x Cultivar = 5.5

* Each value is the mean of 12 plants (three plants in four blocks). Each plant had from seven to eleven leaves.

† Mean from October 20 through November 30, 1980 (0900 to 1600 EST).

other cultivars. However, "Just Right" showed more of an increase in foliar injury when the control (CF) treatment was compared to the NF-4 treatment than did other cultivars (Table 6).

Growth and Yield--

Mean squares from the analyses of variance (Table 7) indicated that shoot and root fresh weight were signficantly affected by block, $O_3$ treatment, cultivar, and row position. There was a significant treatment x cultivar interaction for both growth measures and a position x cultivar interaction for shoot fresh weight.

Plants of all cultivars were significantly smaller in the nonchamber plots (AA) than in chambers receiving charcoal filtered air (CF) or ambient levels of $O_3$ (NF-1) (Table 8).

The cultivars responded differently to the $O_3$ treatments. For shoot fresh weight, "Just Right" was generally more sensitive than other cultivars (Table 8, Figure 14). For root fresh weight, "Tokyo Cross" was not affected by the NF-2 treatment, while other cultivars were showing trends toward decreased weight (Table 8, Figure 15). However, effects on root weight in the NF-3 and NF-4 treatments were relatively uniform for all cultivars (Table 8).

The cultivar x position interaction was probably caused by variation in shoot size of "Just Right" plants; they were unusually large at two positions in several treatments, while plants of other cultivars were relatively uniform, following the position-size pattern discussed previously.

Correlation coefficients determined for shoot fresh and dry weights for plants in one block were > 0.98 for all cultivars. Correlation coefficients for root fresh and dry weights were > 0.97 for three cultivars and 0.93 for 'Tokyo Cross.'

Discussion

Foliar injury from 3 weeks of daily 7 hour exposure to $O_3$ concentrations as high as 0.16 ppm caused some chlorosis of older leaves. However, severe injury resulted from 3.5 hours of exposure to relatively small concentrations of $O_3$ (0.06 to 0.09 ppm) on November 18. Evidently, plants were unusually sensitive due to cool, dark, and wet conditions that occurred for 3 days before exposure.

This experiment was performed under climatic conditions that were less than optimum for turnip growth. Generally, fall turnip crops are harvested before the onset of frequent freezing conditions as experienced in this study. Plants in the AA plots were injured by frost on several occasions, while those in chambers were not affected, apparently because the chambers moderated temperatures. Temperature differences probably caused the plants in the AA plots to grow slower than those in chambers.

TABLE 7. MEAN SQUARES FROM THE ANALYSES OF VARIANCE OF SHOOT AND ROOT WEIGHTS OF TURNIP PLANTS EXPOSED TO CHRONIC DOSES OF $O_3$

| Source | DF | Shoot Fresh Weight | Root Fresh Weight |
|---|---|---|---|
| Block (B) | 3 | 703** | 298** |
| Treatment (T) | 5 | 10137** | 877** |
| Error A | 15 | 55 | 29 |
| Cultivar (C) | 3 | 10543** | 2239** |
| Position (P) | 7 | 147** | 24** |
| C x P | 21 | 90* | 15 |
| T x C | 15 | 495** | 84** |
| T x P | 35 | 59 | 10 |
| T x C x P | 105 | 35 | 6 |
| Error B | 558 | 55 | 10 |

** and * = Significant at 0.01 and 0.05 level of confidence, respectively.

TABLE 8. EFFECT OF $O_3$ EXPOSURE ON GROWTH OF FOUR TURNIP CULTIVARS

| Ozone Treatment | Seasonal Mean 7 hr/day $O_3$ Conc. ppm† | Root Fresh Weight/Cultivar -- g/plant* | | | |
|---|---|---|---|---|---|
| | | Just Right | Purple Top White Globe | Tokyo Cross | Shogoin |
| AA | 0.031 | 5.1 | 3.1 | 6.2 | 1.9 |
| CF | 0.014 | 10.1 | 6.0 | 14.3 | 4.6 |
| NF-1 | 0.034 | 11.2 | 6.1 | 15.3 | 4.0 |
| NF-2 | 0.056 | 8.7 | 4.7 | 14.9 | 3.8 |
| NF-3 | 0.081 | 4.3 | 3.0 | 7.0 | 1.7 |
| NF-4 | 0.096 | 3.8 | 2.4 | 6.3 | 2.1 |

LSD (P = 0.05) Treatment x Cultivar = 1.6

* Each value is the mean of 32 plants (eight plants in each of four blocks).

† Mean from October 20 through November 30, 1980 (0900 to 1600 EST).

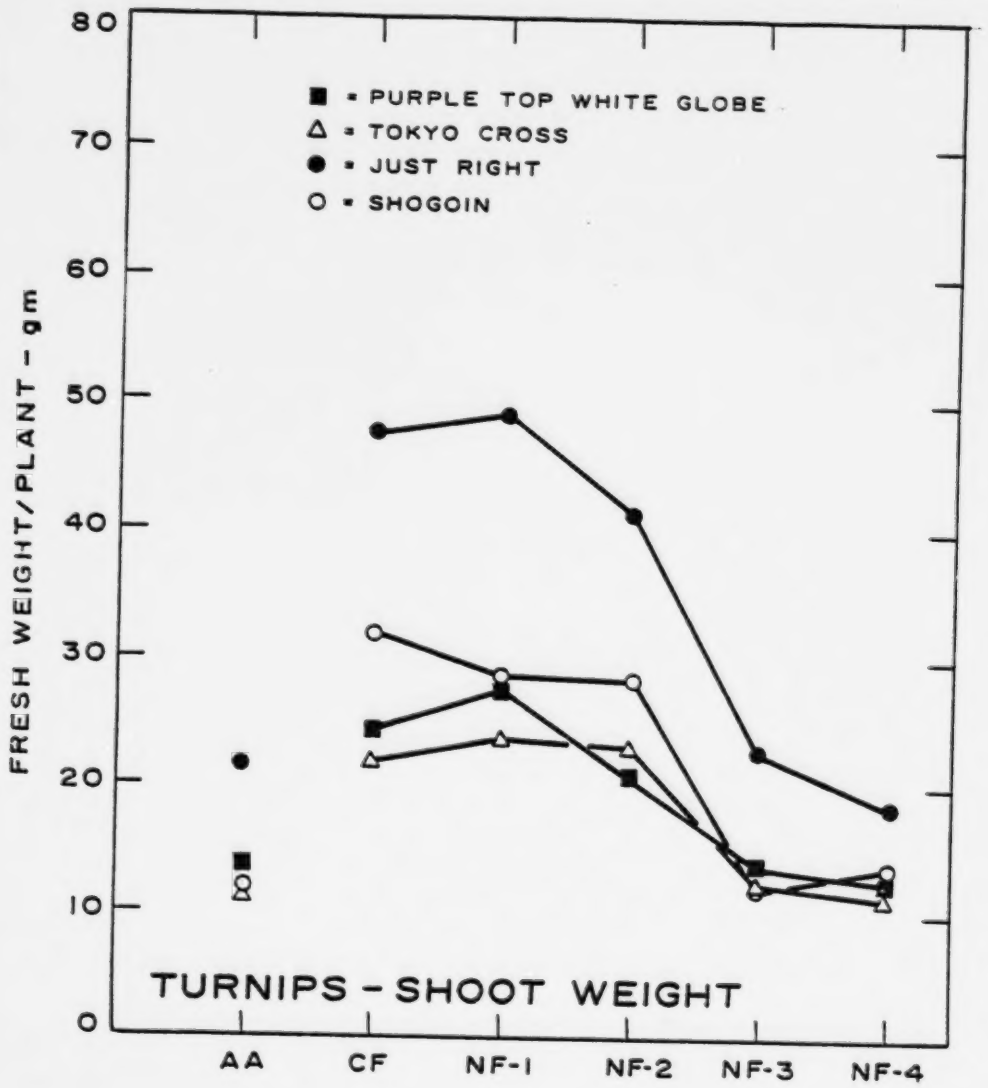


Figure 14. Shoot fresh weight of four turnip cultivars exposed in the open-top ambient conditions (AA), or in open-top chambers receiving charcoal-filtered air (CF) or nonfiltered air with different amounts of $O_3$ added for 7-hr/day (NF-1, 2, 3, 4). Each value is the mean of 32 plants (eight in each of four blocks). Seasonal 7-hr/day average $O_3$ concentrations are shown in Table 8.

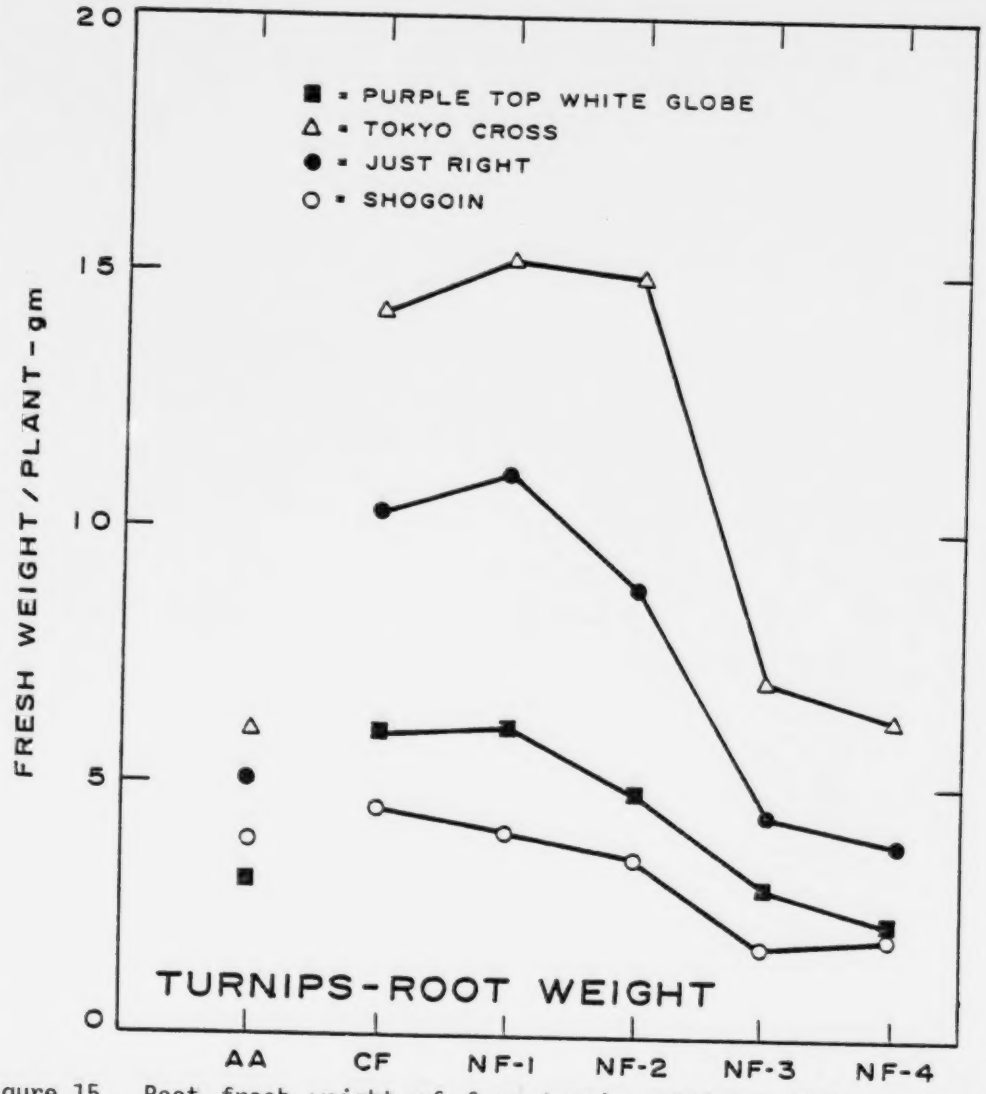


Figure 15. Root fresh weight of four turnip cultivars (AA), or in open-top chambers receiving charcoal-filtered air (CF) or nonfiltered air with different amounts of $O_3$ added for 7 hr/day (NF-1, 2, 3, 4). Each value is the mean of 32 plants (eight in each of four blocks. Seasonal 7-hr/day average $O_3$ concentrations are shown in Table 8. Several regression models were tested on the open-top chamber data. The linear model was significant for all cultivars but the plateau-linear model was significantly better for all except Shogoin. Both models are shown for 'Just Right':

Linear: $Y = 12.91 - 93.6x$ ($Y$ = root fresh weight in grams; $x = O_3$ concentration in ppm).

Plateau-Linear: $Y = 10.69$ if $x \leq 0.0377$;
$Y = 15.47 - 126.7x$ if $x > 0.0377$.

Growth of all cultivars was decreased by $O_3$ doses that occurred in the NF-3 and NF-4 treatments. However, it is difficult to determine the percentage decrease caused by the single 3.5 hour exposure on November 18 which caused severe foliar injury from the percentage decreased caused by the accumulated effects of all other exposures.

NORTHEAST REGIONAL CROP LOSS ASSESSMENT PROGRAM (NERCLAP)--BOYCE THOMPSON INSTITUTE (BEAN)*

The experimental plant used was Phaseolus vulgaris L. The red kidney bean cultivar 'California Light Red' was obtained from Agway (Box 219, RD 2, Yagel Road, Geneva, New York 14456). California Light Red is a late maturing bush cultivar which requires 109 days to reach maturity.

Planting took place on June 13, 1980. Seeds were mechanically planted 3.8 cm deep using a John Deere Planter with a H12255B bean plate calibrated to deliver 12 seeds per meter. Rows were spaced 76 cm apart and oriented east to west. A one-time application of fertilizer (12-24-12, NPK) was made simultaneously with planting in a band 5 cm below and 5 to 7 cm to the side of the seed at a rate of 373 kg/ha.

No preplanting herbicide was applied to the experimental site and only minor hand weeding was done after crop emergence. In accordance with NCLAN policy, no pesticides were applied to the plants during the growing season.

Methods and Materials

Thirty-two days after planting, the open-top chamber frames were placed over the experimental plots. The bean plants were 30 to 45 cm high at the time. Care was taken to insure that three rows of plants were included in each chamber. The locations of the ambient plots were also established at this time.

The chamber frames were covered with Krene and the blowers placed into operation on August 6, 1980. Blower operation was controlled by individual timers set to shut the blowers off between 2000 and 0500 hr EDT to allow dew formation within the chambers.

Ozone exposures began on August 20, 1980, 68 days after planting and during the pod-filling period. Exposures were conducted beginning at 1000 and terminating at 1700 hr EDT. The last exposure was on September 10, 1980. During this period exposure were conducted daily with the exception of August 25.

The 24 points to be monitored, 20 chambers and four ambient plots, were divided into two sets of 12 points each. Each set was monitored using a Scanivalve sequencer (Scanivalve Corporation, San Diego, California), a Monitor Lab Model 8410 $O_3$ monitor (Monitor Labs, San Diego, California), and a Speedomax (Leeds and Northrop, Philadelphia, Pennsylvania) strip chart

* Robert Kohut, John Laurence, and Luke Colavito.

recorder. During the exposures, the Scanivalve was set to monitor each point for 5 minutes before advancing. Between exposures the system was used to monitor ambient $O_3$.

Harvest of the chamber-covered plots took place on October 10 and the ambient plots on October 11. The harvest dates were 119 and 120 days after planting, respectively. All plants growing within 30 cm of the chamber frame were excluded from the harvest. The remaining plants within the plot were counted and all pods on them that contained beans were collected. The pods were counted and separated into two classes: mature and green. No other data were collected for green pods since they contained immature seeds that would not be included in a marketable harvest. The mature pods were dried for 24 hours at 30°C, threshed by hand, and the beans weighed. The moisture content of the beans after drying was approximately 10%.

An open-top chamber frame was placed over each ambient plot to delineate the exact area to be harvested. Since some of the ambient plots had been disturbed during repeated observations of soil moisture, four additional ambient sites which were undisturbed and adjacent to the original ambient plots were delineated and harvested. The harvest procedures for the ambient plots were the same as those employed with the chamber plots including the discarding of all plants within 30 cm of the plot boundary.

## Results and Discussion

Ambient $O_3$ concentrations monitored at the field site generally displayed a diurnal pattern of fluctuation with the highest concentrations occurring in midafternoon. Elevated concentrations of $O_3$ did occur at night on several occasions. However, violations of the National Ambient Air Quality Standard for $O_3$ (0.12 ppm) were not recorded.

The monitoring data from the open-top chambers and ambient plots were evaluated to assess the $O_3$ levels in the treatments. The seasonal 7-hr/day average $O_3$ concentrations for each treatment are shown in Table 9. The ambient air $O_3$ data collected during the exposure period are summarized as daily 7-hr (0900 - 1600 EST) and 24-hr means (Figure 16).

The seasonal hourly average $O_3$ concentrations for the treatments are shown in Figure 17. The diurnal pattern of ambient $O_3$ concentration fluctuation can be seen in this figure. In addition, the incremental treatment levels and effect of charcoal filtration are evident.

The California Light Red kidney bean plants used in the open-top chamber study were routinely examined for air pollution, insect, and biotic disease injury and received two in-depth assessments on September 4 and 24. During the assessment on September 4, foliar $O_3$ injury was observed in several of the chambers. Injury was most consistently observed in the NF-3 and NF-4 chambers; six of the eight chambers receiving these treatments contained plants with foliar $O_3$ injury.

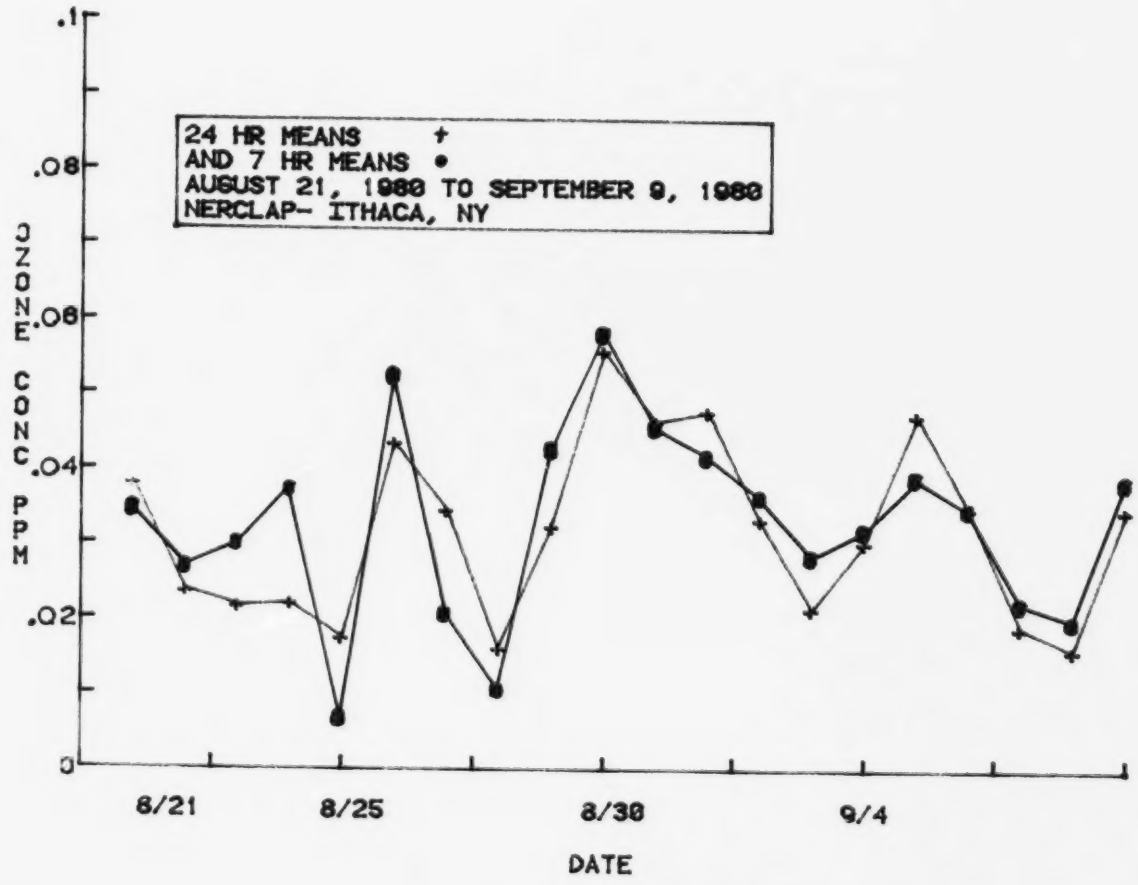


Figure 16. Comparison of the 24-hr and 7-hr mean ambient ozone concentrations for the monitoring period.

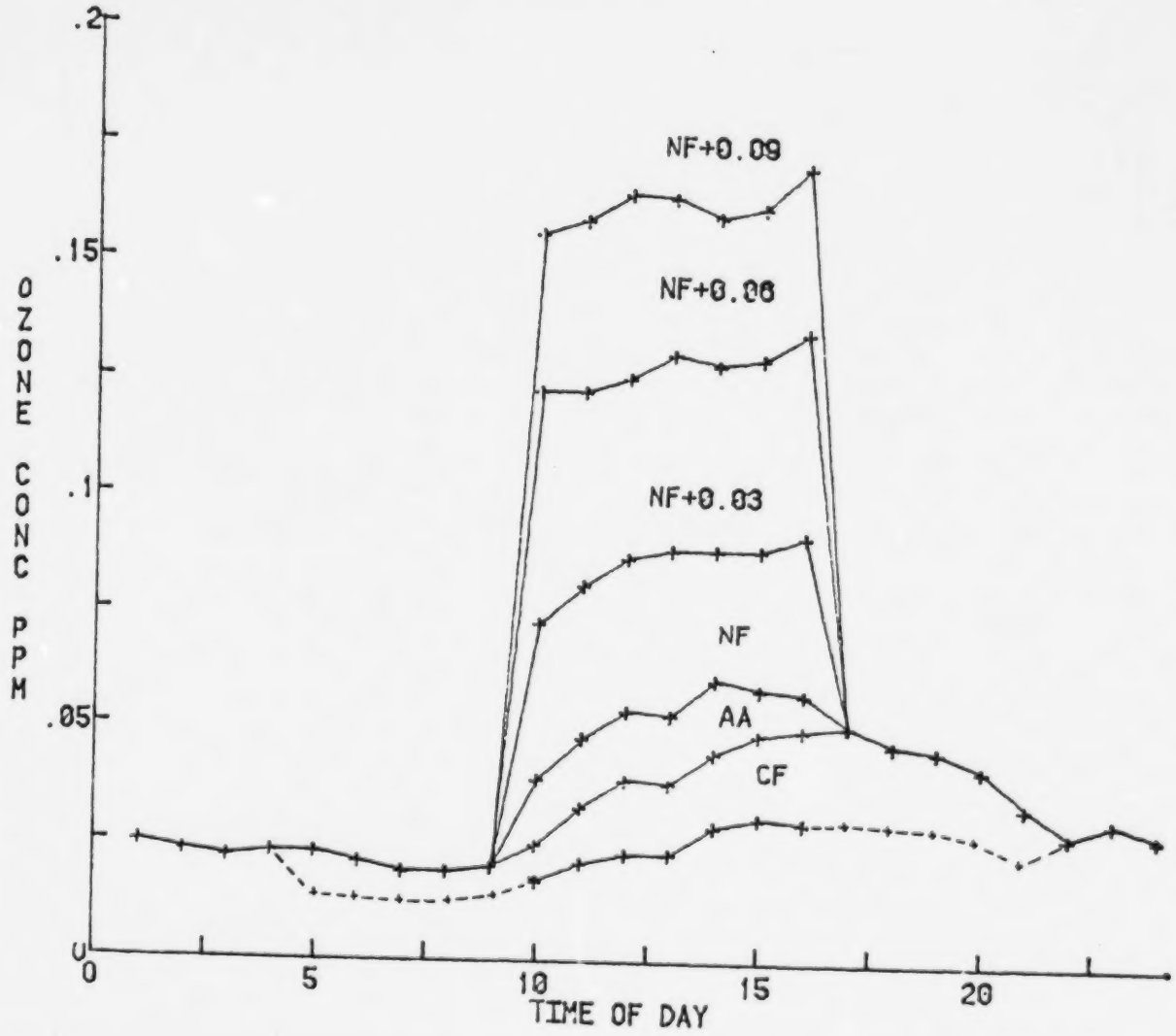


Figure 17. Seasonal hourly ambient $O_3$ concentrations for the charcoal filtered (CF), ambient air (AA), nonfiltered (NF − 1), and nonfiltered with added $O_3$ treatments. Charcoal filtered from 0500 to 1000 and 1700 to 2200 are estimates. The 7-hr/day mean $O_3$ concentration for each treatment from August 20 through September 10 are 0.025 ppm (CF), 0.040 (AA), 0.053 (NF − 1), 0.086 (NF - 2), 0.128 (NF - 3), and 0.162 (NF - 4).

TABLE 9. MEAN $O_3$ CONCENTRATION, YIELD, AND POD PRODUCTION IN KIDNEY BEAN FOR EACH TREATMENT

| Treatment | Ozone Concentration* (ppm) | Plant Response | | | |
|---|---|---|---|---|---|
| | | Dry Weight Yield/ Chamber (g) | Number of Pods | | |
| | | | Mature | Green | Total |
| AA (Disturbed) | 0.040 | 1142 | 498 | 93 | 591 |
| AA (Undisturbed) | 0.040 | 1176 | 563 | 132 | 694 |
| CF | 0.025 | 1307 | 671 | 61 | 732 |
| NF - 1 | 0.053 | 1276 | 654 | 49 | 703 |
| NF - 2 | 0.086 | 1248 | 679 | 62 | 740 |
| NF - 3 | 0.128 | 1086 | 628 | 18 | 646 |
| NF - 4 | 0.162 | 954 | 581 | 28 | 609 |

* Seasonal 7-hr/day mean $O_3$ concentration (August 20 - September 10).

The next assessment of the plants in each chamber was conducted on September 24. The most pronounced condition observed was the considerable defoliation which had occurred in certain chambers. The maximum leaf retention observed in the NF-3 and NF-4 chambers was 40%. This can be compared with the nearly full leaf retention found in the AA and CF air treatments. Intermediate levels of leaf retention were found in the N-1 and NF-2 chambers.

In addition to $O_3$ treatment, leaf retention was also influenced by the location of the chamber within the study area. The block of treatments located in the western or drier end of the study area showed lower leaf retention than did the other three blocks. It is believed that the lower soil moisture and higher incidence of powdery mildew in this portion of the study area contributed to the premature defoliation.

The data collected from the plants in the open-top chambers included the number of plants, the number of mature pods, the number of green pods, and the dry weight of the bean yield for each chamber. The experimental design consisted of four blocks each containing all of the treatments. Plants in the study block at the eastern end of the open-top chamber field site failed to mature at the same rate as those in the other blocks. Since the pods on these plants were immature and not ready for harvest, this block was dropped from the analysis and the data from the other three blocks were used in the assessment of impacts. The data were evaluated by analysis of variance. The treatment sum of squares was partitioned into orthogonal contrasts for filtered vs nonfiltered, chamber vs no chamber, disturbed plot vs nondisturbed plot, and linear, quadratic and cubic components of the $O_3$ dose. The results of the contrast analysis are summarized in Table 10.

The analysis indicated a significant block effect for pod dry weight. However, there were no significant block by treatment interactions. These results indicate that establishing blocks within the open-top chamber study area was appropriate and that the treatments produced similar responses in each of the blocks.

Regression analysis was used to examine the relationship between yield and average $O_3$ concentration. The data used in the analysis and the regression equations produced are presented in Table 11. The analysis for $O_3$ concentration and yield showed a good linear fit with a correlation coefficient of 0.96. The nature of the relationship between pollutant exposure (7-hr/day mean $O_3$ concentration) and yield is shown in Figure 18.

SOUTHWEST REGIONAL CROP LOSS ASSESSMENT PROGRAM (SWRCLAP)--UNIVERSITY OF CALIFORNIA, RIVERSIDE (HEAD LETTUCE LACTUCA SATIVA L. CV EMPIRE)*

Crop loss assessment studies for the Southwest region of the National Crop Loss Assessment Network were initiated at Riverside, California during the spring and summer of 1980.

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* O. C. Taylor.

TABLE 10. CONTRAST ANALYSIS OF OPEN-TOP CHAMBER DATA FOR KIDNEY BEAN

| Dependent variable | Block x treatment (error) MS | Block | Contributions to sum of squares[a] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Disturbed vs nondisturbed ambient[b] | Chamber vs no chamber[c] | Filter vs no filter[d] | $O_3$ Dose added-on[e] | | |
| | | | | | | Linear | Quad | Cubic |
| Plant/sample | 3.29 | 0.74 | 0.44 | 10.31+ | 10.31+ | 5.38 | 10.89 | 0.18 |
| Mature pods | 313.22 | 442.50 | 1045.44+ | 8981.35** | 2316.34** | 127.21 | 578.00 | 60.84 |
| Green pods | 167.53 | 303.50 | 367.36 | 3371.21** | 149.51 | 214.67 | 387.72 | 25.60 |
| Pod Dry Weight | 1775.30 | 15532.54** | 275.89 | 168.98 | 30318.24** | 9815.69* | 4642.95 | 3.82 |

[a] F values were determined by the ratio of the block or treatment contrast mean square to the Block x Treatment mean square.
+ = Pr (value > F critical) < 0.10.
* = Pr (value > F critical) < 0.05.
** = Pr (value > F critical) < 0.01.

[b] This compares the disturbed (4) and nondisturbed (4) ambient plots.

[c] This compares all the chamber plots (20) with the nonchambered plots (8).

[d] This compares the filtered chambers (4) with the nonfiltered chambers (16).

[e] This analysis used all the chamber treatments in which $O_3$ was added.

TABLE 11. REGRESSION ANALYSIS OF KIDNEY BEAN YIELD AND $O_3$ DOSE[1]

| Treatment | Seasonal 7-hr/day Average $O_3$ Concentration (ppm) | Yield/Plant (g) |
|---|---|---|
| CF | 0.025 | 16.1 |
| NF-1 | 0.053 | 15.8 |
| NF-2 | 0.086 | 15.2 |
| NF-3 | 0.128 | 12.2 |
| NF-4 | 0.162 | 11.8 |

[1] The AA treatment was not significantly different from NF-1 and thus was included in the regression analysis. Several regression models were tested but none gave a better fit than the linear: $Y = 17.44 - 35.51x$ where Y = yield in g/plant and X = $O_3$ concentration in ppm.

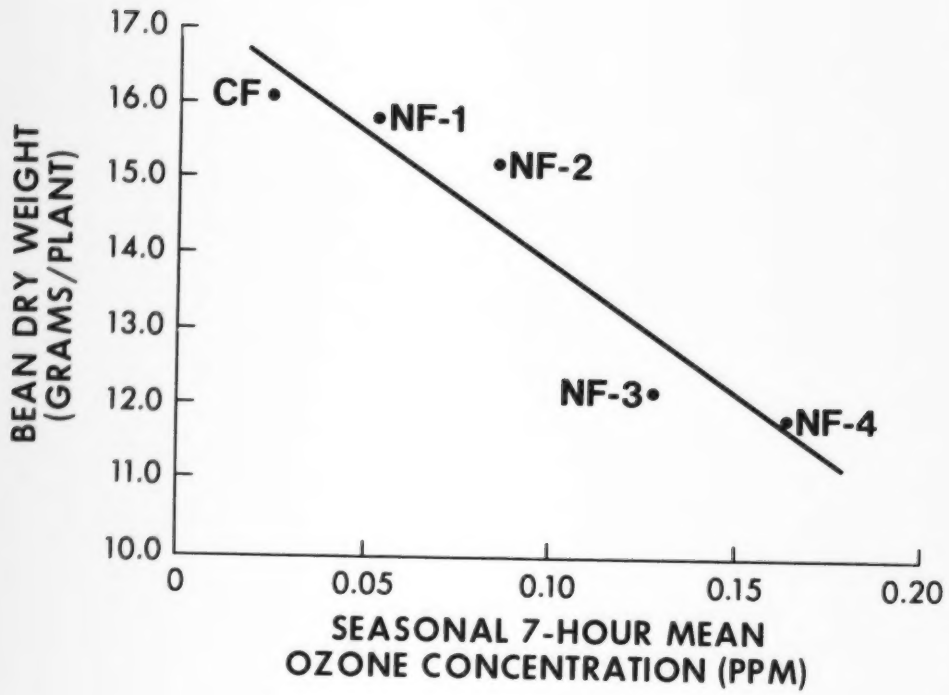



Figure 18. The relationship between the seasonal 7-hr/day mean $O_3$ concentration in the chamber treatments and dry weight yield of kidney bean. A linear function provided the best fit to the data (Table 11).

Because of funding delays, it was not possible to start the exposure experiments early enough to use such summer growing crops as cotton, alfalfa, or beans. Head lettuce, cv. 'Empire,' was used for the first test, since it is normally planted in the field in the desert areas of the Southwest about mid-August.

Soil in the field plots at the Agricultural Experiment Station is a relatively young decomposed granite type in the Breenfield series. It is deep with no identifiable (B) horizon or plow sole. It is friable and granular when moist, but sets up relatively hard when dry. Fertility is generally good but nitrogen is typically low for optimum plant growth. The field is flat with a very gentle slope to the west to allow for irrigation through straight furrows. The plot was plowed in the spring soon after new weed growth began. It was disced twice to remove the weeds.

## Materials and Methods

Pelletized seeds of the Empire lettuce were germinated in Jiffy pots in a greenhouse soil mix. When two or three true leaves had developed, the plants were transferred to the field in the areas where the chambers were to be installed. Plants were set 30 cm apart in rows spaced at 75 cm.

At the time of planting, a band of nitrogen was placed below the root zone. After approximately 3 weeks, when the plants were well established and growing vigorously, a side dressing of nitrogen was applied at a rate equal to 200 pounds per acre.

Weeds were removed from the chambers by hoeing and hand pulling. Since irrigation was confined to the chamber areas, weeds were not a problem in the area between chambers.

Two irrometers were placed near the center of each open-top chamber at depths of 45 and 60 cm and the vacuum guage reading was recorded daily. The plot was irrigated when soil suction reached 30 on the irrometer gauge.

A drip irrigation system was installed in each plot. This consisted of a commercially available system of thin walled plastic tubes with small holes that slowly released water along the rows. There was no runoff to soak surrounding areas, but sufficient water could be applied to soak deeply into the soil.

The $O_3$ treatments used at this site were different than those at the other NCLAN location due to the high ambient $O_3$ concentrations. The treatments at SWRCLAP were: 1) ambient air plots (AA) without chambers; 2) ambient air open-top chambers (2 space sets) with 0.015 ppm $O_3$ added to make up for loss in the blower and chamber duct (NF-1); 3) two-thirds ambient (NF-2/3) chambers with activated charcoal removed from 2/3 of the filter holders; 4) one-third ambient (NF-1/3) in chambers with activated charcoal removed from 1/3 of the filter holders; 5) charcoal filtered (CF) chambers; and 6) ambient air open-top chambers plus 0.09 ppm ozone (NF-3).

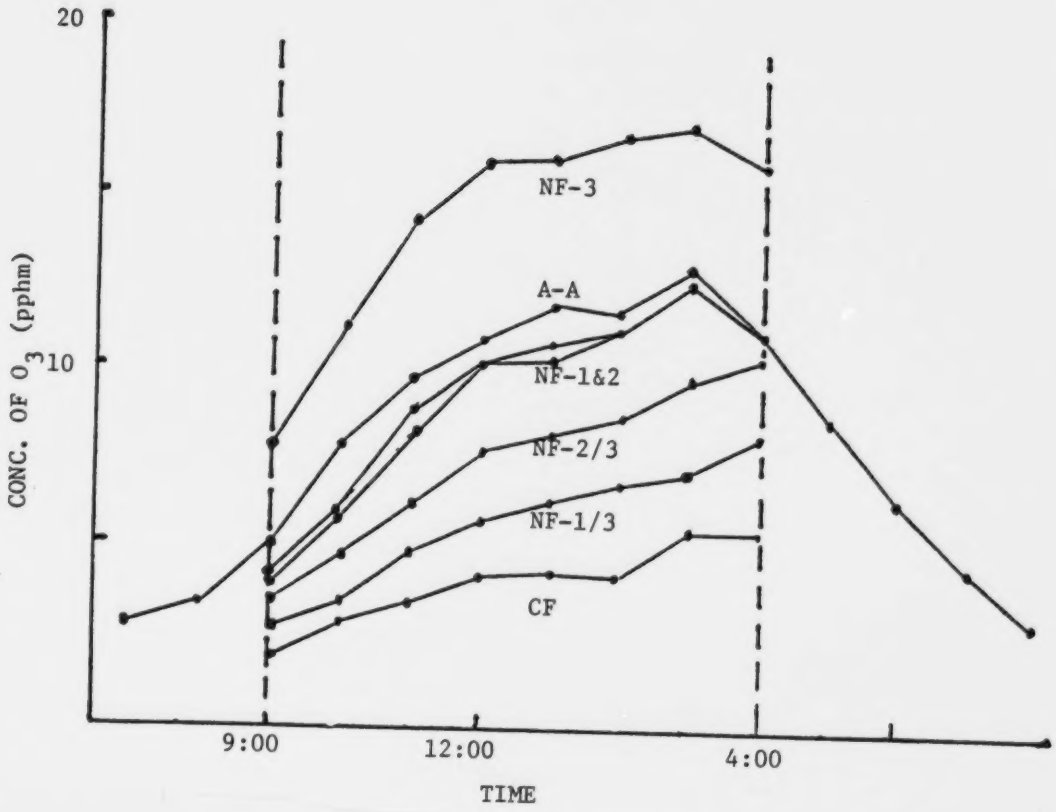
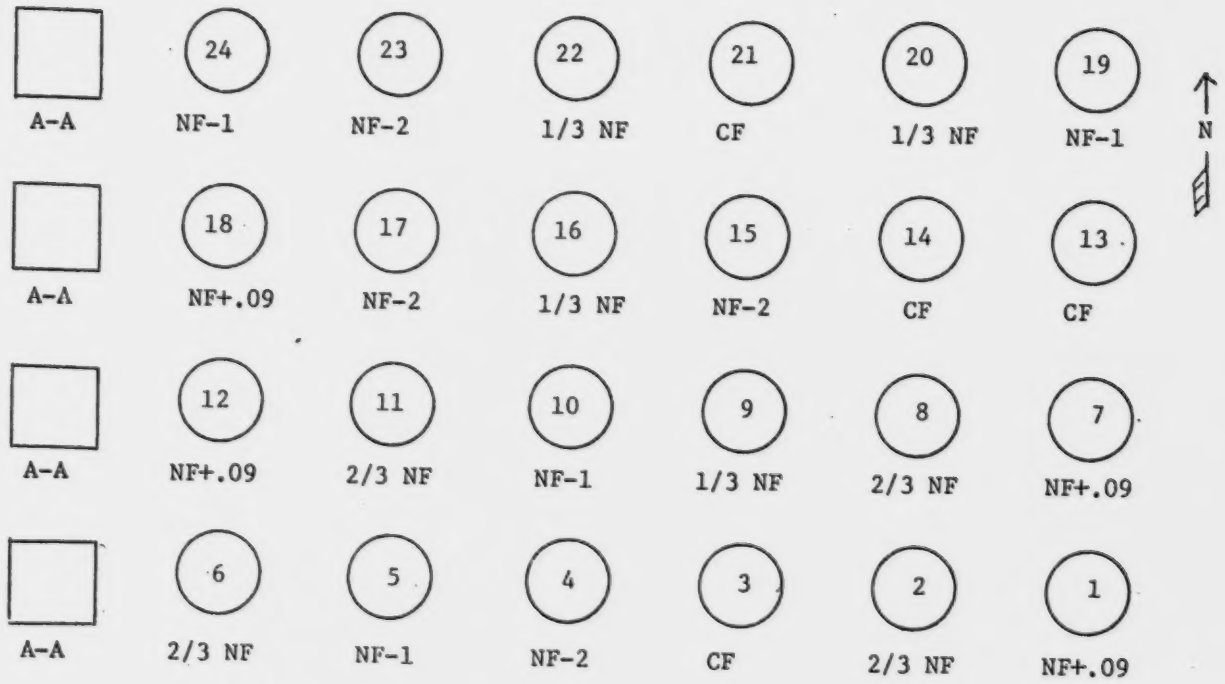



Figure 19. Hourly average ozone recorded between September 24 and November 13, 1981. The treatments represented are: NF-3, ambient air plus 0.09 ppm $O_3$; A-A, ambient air outside the chambers; NF-1 and 2, two replications of 4 chambers each with ambient air plus 0.015 ppm $O_3$; NF-2/3, activated charcoal removed from 1/3 of the filters; NF-1/3, activate charcoal remove from 2/3 of the filters; and CF, activated charcoal filtered air.




USDA chambers at 25 foot spacing, center to center

Figure 20. Diagram of plot and chamber locations and air pollutant treatments. Ambient air (A-A) plots (no chambers) were placed for convenience as indicated, and other treatments were completely randomized within one block using a statistical table.

The effectiveness of removing activated charcoal from part of the filter holders to attain a desired proportion of filtered and ambient air (1/3 and 2/3 of ambient) was verified by comparing recordings from the monitoring instruments. The partial filtration did not accurately produce the concentrations of ozone desired but there was reasonable spread in average concentration between these chambers and the nonfiltered chambers (Figure 19).

Two Dasibi $O_3$ monitors, connected through a 12-port valve system, were used to record $O_3$ levels in each chamber. A third Dasibi instrument was dedicated to monitoring ambient $O_3$. A fourth Dasibi instrument was used as a mobile calibrating reference. This mobile instrument is routinely taken to the California Air Resources Board (CARB) laboratory in El Monte for calibration.

Ambient $SO_2$ was monitored at the plot site with a Meloy instrument. Ambient $SO_2$ was essentially zero during the study period. On rare occasions there was a slight deflection of the recorder pen, but not sufficient to read.

The open-top chambers were modified using a nozzle attachment designed by Kohut et al. (15) and tested by Davis and Rogers (17). The nozzle reduced the top opening of the chambers from 3-m to 2.13-m in diameter. These nozzles were not installed on the chambers during the first 2 weeks. During this period the $O_3$ concentrations in the chambers fluctuated, particularly during the afternoon when the marine air flow increased in velocity. As soon as an acceptable frame was built for the nozzles, they were installed and a marked improvement in stability of $O_3$ concentration was apparent.

The open-top chambers were placed in a rectangular pattern with 4 rows of 6 chambers each (Figure 20). Since underground electrical wiring and water was provided for only 24 chamber sites this first year, it was necessary to locate the four plots without chambers at the west end of the experimental areas. The ozone treatments were completely randomized between chambers and no effort was made to divide the plot into 4 replicate areas since there was no indication of significant variability between the 28 positions selected.

## Results and Discussion

The open-top chambers were set in place and the blowers were started on September 1 but because of difficulties with the monitoring instrumentation and ozone dispensing system the addition of ozone to the NF-1, 2, and 3 treatments was delayed until September 24. Consequently, the treatments with added ozone operated for seven (7) weeks during the growing season for the lettuce. The average concentration of ozone measured in each treatment during the 8 hour period between 9:00 a.m. and 5:00 p.m. is shown in Figure 19. The average ozone concentration in the carbon filtered chambers (CF) at 3:00 to 4:00 and 5:00 p.m. was 0.05 ppm and during this same period the average concentration in outside ambient air was 0.13 and 0.11 ppm respectively. The ozone in the CF treatment came from subsidence through the open chamber top when late afternoon winds started to blow as well as from some leakage around the carbon filters. On two different days during the experiment the hourly average ozone concentration in the NF-3 (ambient plus 0.09 ppm) was 0.32 ppm and on several occasions it reaced an hourly average of 0.29 to 0.30 ppm.

A random sampling of lettuce plants was selected in each plot for estimation of foliar injury symptoms. These plants were examined by the same person each week and the amount of leaf injury was recorded. Differences in amount of visible injury and in rate of growth of the plants became very obvious by early October. The highest $O_3$ levels definitely suppressed growth and increased foliage injury.

Lettuce planted in late August is expected to mature and be ready for harvest for the Christmas market. It was anticipated that the plots would be ready to harvest about December 15. However, on November 13, a Santana wind condition developed and for almost 3 days there were strong winds, gusting up to 50 and 60 miles per hour. The chambers were watched closely for damage and aside from some small damage to some of the nozzles it looked like they would withstand the winds. On November 16 wind velocity increased to an estimated 89 to 90 mph and a number of the chambers were damaged; some were blown loose from their anchors. On November 17, the lettuce was cut and weights were taken. Because of the wind disturbance only total weight per plant was calculated from these data.

Data from this experiment should be used with care for crop-loss assessment purposes because of the severe treatment at the end of the experiment and because the crop had not matured sufficiently for normal marketing. Average weight per plant is presented in Table 12 and Figure 21 to indicate the trends in growth response to the five dosages of $O_3$. The addition of 0.09 ppm $O_3$ (NF-3) to the ambient levels for 7-hr/day suppressed plant growth more than the other treatments; the NF-1 and 2 treatments, where 0.015 ppm $O_3$ was added to ambient air, and the plots without chambers were intermediate in growth and were similar in size.

TABLE 12. ANALYSIS OF VARIANCE OF AVERAGE WEIGHT/PLANT OF HEAD LETTUCE (*LACTUCA SATIVA* L. CV EMPIRE) EXPOSED TO 5 DOSAGES OF OZONE

| Treatment | Plant Weight Mean (g) | Significance 5% | Significance 1% |
|---|---|---|---|
| CF Carbon Filtered | 848 | x | x |
| NF - 1/3 | 744 | x y | x |
| NF - 2/3 | 657 | y | x y |
| NF-1 | 431 | z | y z |
| NF-2 | 411 | z | y z |
| A-A No Chamber | 404 | z | y z |
| NF-3 | 248 | z | z |

Treatment mean square = 0.18870.

Replication mean square = 0.18891.

Error mean square = 0.14657.

Note: NF-1 and NF-2 received 0.015 ppm $O_3$ added to ambient air and NF-3 received 0.09 ppm $O_3$ added to ambient air.

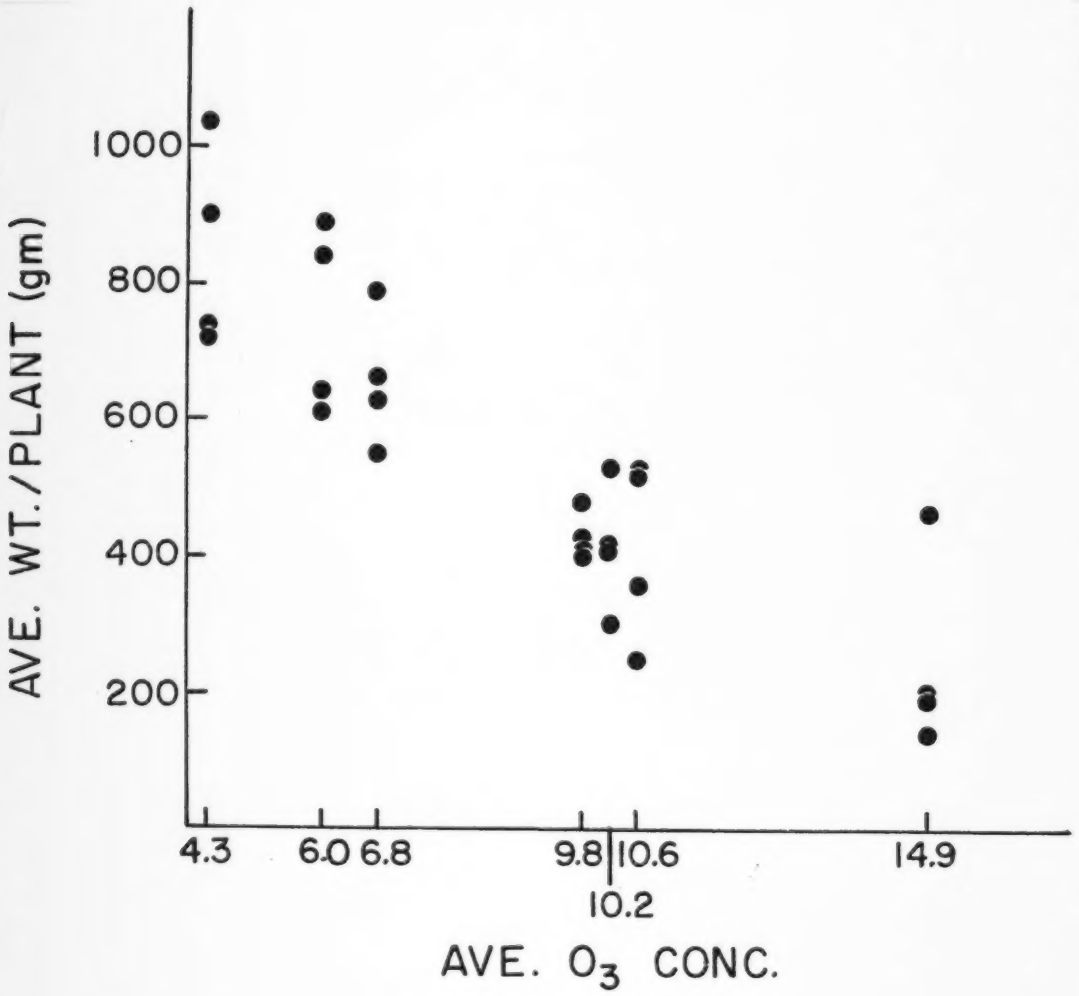



Figure 21. Average plant weight of lettuce (Lactuca sativa L. CV Empire) exposed to the indicated $O_3$ concentrations for 7 weeks. Treatment designations are 0.043 ppm -- CF; 0.06 ppm -- NF-1/3; 0.068 ppm -- NF-2/3; 0.0098 ppm -- NF-1; 0.102 ppm -- A-A; 0.106 ppm -- NF-2; and 0.149 ppm -- NF-3.

SECTION 5

# EFFECTS OF MIXTURES OF SULFUR DIOXIDE AND OZONE ON TOMATO: OPEN-TOP CHAMBERS (SERCLAP)*

The field program at Beltsville, Maryland (SERCLAP) studied the effect of additions of low concentrations of $SO_2$ on crop productivity when plants were grown at two levels of $O_3$ (charcoal filtered ambient air vs nonfiltered ambient air). In 1979, the results on snapbean (18) showed an more than additive effect of $SO_2$ in the chambers with the higher $O_3$ concentrations. This work was repeated for tomato as part of the 1980 NCLAN program.

## Materials and Methods

Field plots were located at the U.S. Department of Agriculture Research Center (14.5 km northeast of the District of Columbia). The soil was Codorus Sandy silt loam, containing about 65 percent sand, 11 percent clay, and 24 percent silt. The top soil layer was deep and uniform. A nearby creek provided water for irrigation. Prior to land preparation, each of 27 (7.6 x 7.6 m) subplots in three blocks with nine plots in each were sampled to determine soil pH, magnesium, phosphate, and potash. The soil pH ranged from pH = 5.7 to 6.8. Lime was added to bring all subplots to pH = 6.5. Soil tests indicated high magnesium and phosphate concentrations and medium potash levels. Just prior to transplanting, 560 kg/hectare of 5-10-5 fertilizer was broadcast and disced into the soil. An additional 280 kg/hectare of 10-10-10 was applied September 11 as a top dressing. At transplanting, a soluble fertilizer (20-20-20) was applied using 1.2 g per liter and 1.2 liter per plant. On May 30, six plants of the tomato cultivar "Jet Star" were transplanted in each chamber. They occupied three quadrants of the chamber, an area 6 $m^2$ in size. The soil moisture tensiometers were placed in each chamber center at 25 and 40 cm depths. In addition, at various intervals during August and September, measurements of soil moisture were made on 2.5 cm diameter cores taken at 15 or 30 cm depth. The plots were hand weeded. Each tomato plant was placed in a 1.37 m high, 0.53 m diameter wire cylinder made with 15 cm woven mesh. Plants were not pruned. The branches were kept within the cylinders until the plants grew out of the cylinder tops. The plant tops were further supported with light ropes tied to four 5.0 cm x 5.0 cm x 2.4 m high stakes. Plants in some plots averaged 229 cm (7.5 feet) by the end of the season.

The ripe tomato fruits were harvested from each plant separately. There were 10 weekly harvests beginning July 28 and continuing to September 29. The fruits were weighed individually to evaluate treatment effects on fruit size and number. On September 30, all of the remaining green fruits (larger than

* H. E. Heggestead, J. H. Bennett, and E. H. Lee.

10 g) were harvested in a final picking. Plant measurements were taken every 2 weeks. Stem diameters near the ground were determined at the end of the season. Plant fresh and dry weights (without fruits) were also obtained to permit an assessment of the total plant biomass.

Leaf samples were taken from the top, middle, and bottom of the plants at monthly intervals; that is, after 1, 2, and 3 months of $SO_2$ treatments. Plant analyses included sulfur and nitrogen contents and concentrations of other mineral elements measurable by x-ray fluorescence. Fruit quality was evaluated by the following physical and subjective tests: total activity, pH, reduced ascorbic acid content, color, texture, and taste quality. Samples of the fruits were freeze-dried and chemically analyzed as described for the leaves. Leaf injury and senescence was estimated every 2 weeks, beginning in mid-July, after 2 weeks of $SO_2$ treatments.

The $SO_2$ exposure treatments were: 0, 0.06, 0.12, 0.24, and 0.48 ppm in nonfiltered (NF) air and 0, 0.12, and 0.48 in carbon-filtered (CF) air. The treatments were given for 5-hr/day, 5 days/week except on days with rain or with winds greater than 16 km/hour. The chambers were monitored using 63 mm OD Teflon tubing to sample air from each chamber. As in 1979, the air intake was 1/2 m above the ground on the west side of each chamber and equidistant between the chamber panel and the tomato foliage. The effects of $SO_2$ on soil pH and exchangeable aluminum were evaluated using soil samples from the upper 8 cm in each plot.

Sulfur dioxide was monitored with a Model 43 Thermo-Electron pulse fluorescent $SO_2$ analyzer. A Model 143 Thermo-Electron permeation tube calibrator was used to calibrate the analyzer. Each chamber was monitored sequentially for 3 minutes using the last minute of each period to indicate the chamber $SO_2$ concentration. The $SO_2$ dispersing and monitoring system was similar to that described by Heagle et al. (8) for $O_3$ delivery and control. Utilizing experience gained in the 1979 season, the solenoid control unit was modified and improved by Tuthill Electronics, Southold, New York.

Ozone was monitored with a Bendix Model 8002 chemiluminescent analyzer. Late in the season an additional Model 1003 Dasibi $O_3$ monitor equipped with a calibrator was also used.

The chambers were turned off 7 hours each night between 2200 and 0500 EST. Irrigation was accomplished using a pump at the creek to deliver water through hoses. The equivalent of 1.3 cm rain per day was applied when tensiometer readings exceeded 0.6 atmosphere. As soon as the soil dried adequately, it was loosened (tilled) to a depth of about 7.6 cm.

The yield data was summarized and an analysis of variance run. The Duncan Multiple Range was used to test mean differences at $P = 0.05$.

## Results and Discussion

The effects of $SO_2$ and oxidants ($O_3$) on tomato yield were additive (Table 13). Ambient oxidants reduced fruit yield about the same as the highest $SO_2$ dose (0.48 ppm $SO_2$) applied in charcoal-filtered air (i.e., 16.6 and 17.8%),

respectively, based on yields in CF air. The combination of 0.48 ppm $SO_2$ and atmospheric oxidants resulted in a yield loss of 31.5%. Regression data indicated that effects of the various $SO_2$ treatments remained almost constant after about the fourth week of the 10-week harvest period.

Plants in the chambers were about 0.5 m taller than plants grown without chambers (AA). Fruit yields in the AA plots were 74 percent of those in non-filtered air chamber.

The regression analyses between $SO_2$ exposure dose and reduced tomato yield in both NF and CF are shown in Figure 22.

The targeted $SO_2$ concentrations (0.06, 0.12, 0.24, and 0.48 ppm) were almost the same as the measured concentrations. Concentrations were somewhat less in chamber centers after $SO_2$ passed through the canopy. The sample intake was between the duct and the outside edge of the tomato canopy.

Effects of $SO_2$ were observed in both fruit size and number in the 1980 experiments, whereas in 1979 only fruit size was affected. No adverse effects of the $SO_2$ treatments were found on fruit quality. Sulfur content of leaves increased with the $SO_2$ dose, but the sulfur content of fruits tended to be the same regardless of $SO_2$ treatment.

The variation in soil pH after exposure to 0.12 ppm $SO_2$ or less was not significant (Table 14). However, the higher $SO_2$ concentrations significantly decreased soil pH. A high linear correlation was found between $SO_2$ exposure concentration and soil $SO_4$-S levels at the end of the exposure period ($r = 0.95$). The highest $SO_2$ exposure dose caused exchangeable Al in the surface soil to increase more than tenfold from 0.40 to 5.79% of the total exchange capacity.

TABLE 13. TOMATO YIELD LOSSES FOLLOWING EXPOSURE TO SULFUR DIOXIDE AND OZONE, 1980, BELTSVILLE, MARYLAND

| Treatment | | | Yield as Percent of CF (control) (%)[4] |
|---|---|---|---|
| $SO_2$[1] (ppm) | $O_3$[2] (ppm) | Chamber[3] | |
| 0.00 | 0.015 | CF | 100 a |
| 0.12 | 0.015 | CF | 95.0 ab |
| 0.48 | 0.015 | CF | 82.2 bcd |
| 0.00 | 0.056 | NF | 83.5 bc |
| 0.06 | 0.056 | NF | 78.5 cde |
| 0.12 | 0.056 | NF | 75.5 cdef |
| 0.24 | 0.056 | NF | 67.0 ef |
| 0.48 | 0.056 | NF | 68.5 def |

[1] Background $SO_2$ concentrations averaged less than 0.002. Peak $SO_2$ concentrations in the control plots (CF) were ≤ 0.01 ppm. $SO_2$ added 5 hr/day, 5 days/wk, 57 days between July 2 and September 29.

[2] Seven-hour average, 1100 - 1800 hours, July, August, September.

[3] CF, carbon-filtered; NF, nonfiltered, ambient air in open-top chambers.

[4] Treatments followed by the same letter are not significantly different.

TABLE 14. EFFECTS OF $SO_2$ EXPOSURE IN OPEN-TOP CHAMBERS ON THE SOIL pH AND EXCHANGEABLE ALUMINUM

| Sulfur Dioxide Concentration (ppm) | Soil pH[1] Change (pH units) | Exchangeable Al (meq/100 g soil) | |
|---|---|---|---|
| | | Change | % Al Saturation |
| 0 | -0.34 a | 0.09 | 0.40 a |
| 0.06 | -0.36 a | 0.11 | 1.51 ab |
| 0.12 | -0.44 ab | 0.12 | 1.80 ab |
| 0.24 | -0.60 bc | 0.20 | 2.71 b |
| 0.48 | -0.83 c | 0.39 | 5.79 c |

[1] Column means followed by the same letter are not significantly different at P = 0.05.

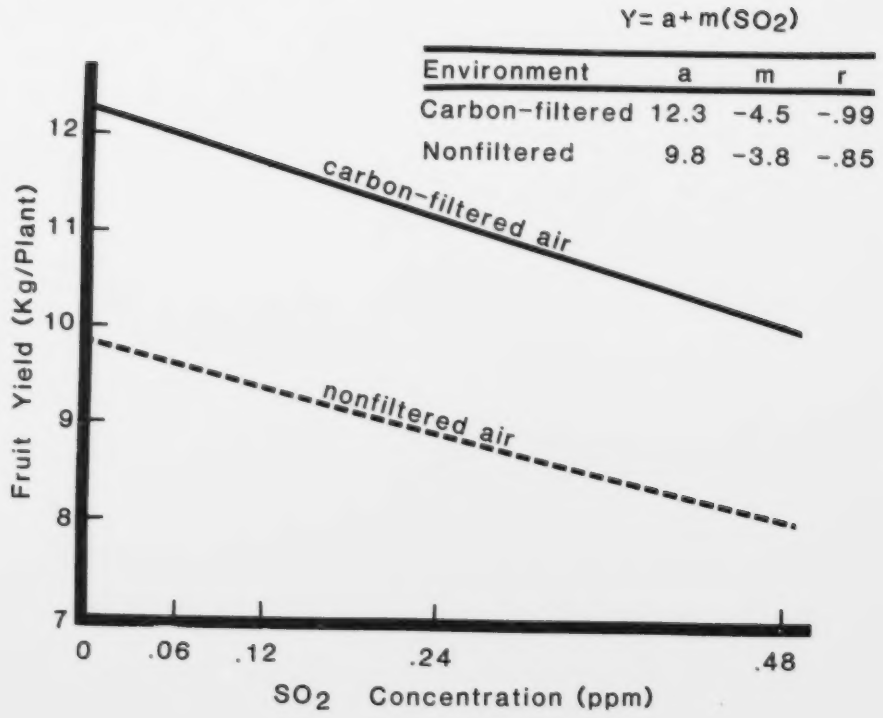



Figure 22. Tomato fruit yields in response to increasing concentrations of $SO_2$ applied (5 hr/day 5-day/week, total 275 hours) in open-top chambers with either carbon-filtered or nonfiltered air.

## SECTION 6

## SULFUR DIOXIDE DOSE RESPONSE FUNCTIONS: ZAPS

The ZAPS technique (Figure 23) was used at three regional sites (CS, SE, NE) during 1980. Two areas of ~ 50 x 20 m were planted using appropriate methods. Eight treatment plots were identified (the second through the ninth rows downwind from the release pipe). Each consisted of a 20 m row segment divided into four 5 m sections that served as samples for each treatment. The second through the fifth rows upwind from the release pipe were the control plots. The design was replicated.

Sulfur dioxide exposures were conducted twice weekly (on the first two favorable days) from the early vegetative stage of growth until normal senescence of the plants. The exposures were of approximately 3 hr duration and were performed between the hours of 0800 and 1600 local standard time. Exposures were performed only when a steady wind (> 3 mph and < 10 mph) intersected the pipe at a 45° or greater angle to assure exposing all of the plots. Exposures were terminated when it rained. Exposures were temporarily terminated with unfavorable changes in the wind direction but were continued when favorable conditions returned.

Sulfur dioxide flows were regulated to achieve mean $SO_2$ concentrations of approximately 0.4 ppm at the second row downwind from the pipe. This resulted in a mean concentration of 0.1 ppm 24 ft downwind under average wind conditions.

### CSRCLAP--ARGONNE NATIONAL LABORATORY (SOYBEAN)*

There are little published data relating reductions in soybean yield to atmospheric $SO_2$ levels. Davis (19) developed a quantitative relationship between leaf damage and yield reductions by exposing plants to brief, severe exposures, but did not indicate the levels of $SO_2$ required to produce specific amounts of damage. Jones et al. (20) found that even when visible injury did occur there was no yield reduction when the injury occurred in the early stages of crop development. Heagle et al. (7) found neither increased visible injury nor yield reductions in field-grown soybeans after 133 6-hr exposures at 0.1 ppm $SO_2$. None of these studies showed what levels of $SO_2$ were required to cause yield reductions or what yield reductions could be expected at given levels of $SO_2$ pollution in chronically impacted areas.

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* Joseph E. Miller and Harry J. Smith.

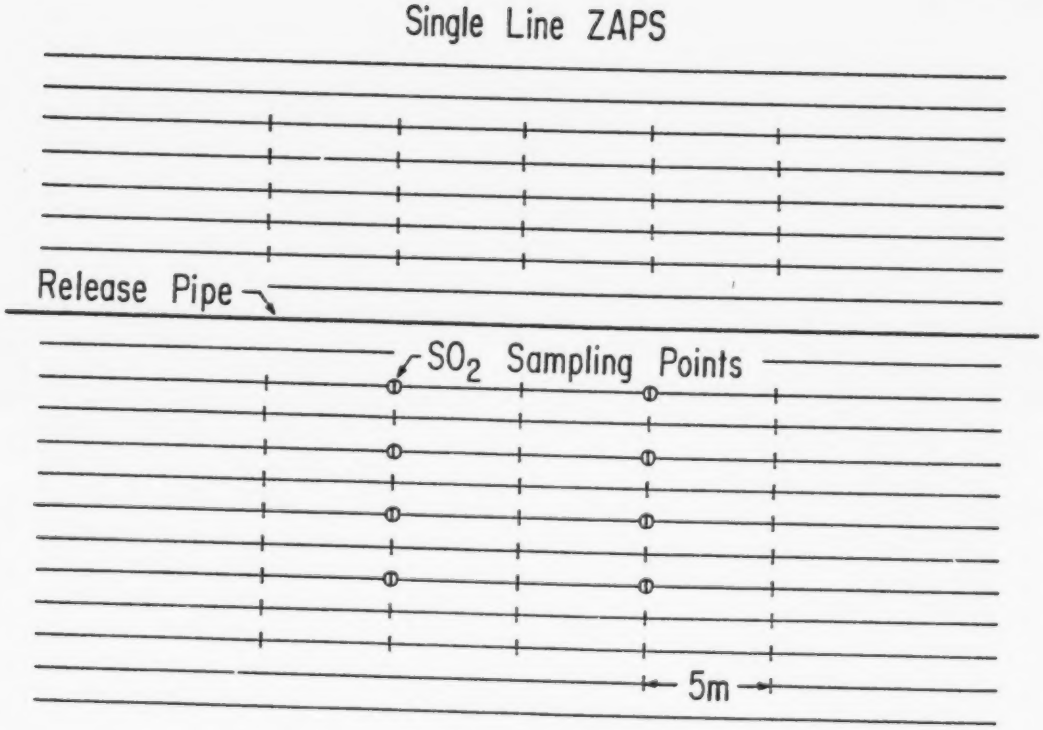


Figure 23. Diagrammatic representation of single line ZAPS system.

## Materials and Methods

'Corsoy' and 'Williams' soybeans [Glycine max (L.) Merr.] were planted at a density of eight seeds per 30 cm in 95 cm rows on July 10, 1980, with a single row mechanical hand planter. The experimental plots were located on a privately owned farm in Kendall County, Illinois, having a Martinon silt loam soil (Aquic Arguidall) with uniform slope and drainage. The field received no fertilization in 1980 but was fertilized with nitrogen the previous year for field corn. Soil test reports from 1980 are not available at this writing, but in previous years the field tested high in phosphorus and potassium with a pH of approximately 6.5.

In early June, the single line ZAPS units were installed in each plot. One Thermoelectron Model 43 (fast response) $SO_2$ analyzer was used for each plot. Multipoint calibrations were performed on each $SO_2$ analyzer every 2 weeks during the experimental period with a permeation tube calibration unit and the span was checked before each use. The $SO_2$ exposures of the rows between monitoring points were estimated by interpolation.

The $SO_2$ treated experimental area consisted of rows 2 through 10 in the prevailing downwind direction from the $SO_2$ release pipe. A control (untreated area) of four rows (rows 2 through 5) was established upwind. Three buffer rows were present at the margins of the plot. The test plots consisted of 5 m row segments in each row (Figure 23).

Nineteen $SO_2$ exposures were conducted between July 16 and September 24. The exposures never exceeded 3 hours and 16 minutes in duration and averaged 2 hours and 34 minutes.

Ambient $O_3$ concentrations were monitored with a Bendix Model 8002 and ambient $SO_2$ was measured with a Meloy Model 160 sulfur analyzer. Malfunction of a portable weather station precluded collection of other environmental data.

Surveys of the plots for visible injury of the leaf tissue were made twice during the growth period. The surveys were made by a single evaluator and were a subjective estimation of the severity of injury and the percentage of leaf tissue injured.

The test plots were harvested on October 2. Each 5 m row segment was harvested in its entirety and threshed with a mechanical plot thresher. The beans were oven-dried to constant weight at 65°C and weighed for estimation of yield effects. Analysis of variance was performed on the bean yield data for both plots using each row as a treatment and the 5 m segments in each row as samples.

## Results and Discussion

The arithmetic mean $SO_2$ concentrations achieved at the monitor locations for all 19 exposures combined (with a total exposure time of 48 hours and 54 minutes) ranged from 0.11 to 0.38 ppm in the Corsoy plot and from 0.11 to 0.40 ppm in the Williams plot. When the monitoring data from the treated plots are

compiled as cumulative frequency distributions for the entire experimental period (Figure 24), it can be seen that the frequency of occurrence of concentrations of 0.11 ppm and greater is similar to that of the ambient monitoring data reported by Loucks et al. (21).

The only visible symptoms of $SO_2$ injury detected in either soybean cultivar was chlorosis which occurred primarily in the upper two-thirds of the canopy. In the Williams plot in late August, the chlorosis was quite obvious and extensive in the rows receiving the two highest $SO_2$ concentrations (0.40 and 0.31 ppm), becoming very mild at 0.18 ppm, and undetectable at concentrations of 0.14 ppm and lower. At the same time, the Corsoy soybean showed milder chlorosis which was detectable only in the rows with mean $SO_2$ concentrations of 0.24 ppm and greater. In both cultivars, senescence of the plants occurred sooner in the three rows receiving the highest $SO_2$ concentrations.

The two soybean cultivars elicited similar yield responses at the three highest $SO_2$ concentrations (an average 14% yield reduction for both Corsoy and Williams; Table 15). However, at the six lower $SO_2$ concentrations the yield of Corsoy was nearly equal to or greater than the controls (averaging 104% of the controls), while the yield of Williams was typically reduced (averaging 92% of the controls). However, the linear regression coefficient for the yield response of the two cultivars were not significantly different at the 5% level indicating that the data may be considered as part of the same population.

The yield response of all soybean cultivars studied in this research group in the past 4 years is summarized as a function of applied $SO_2$ dose in Figure 25. These doses were all generated with chronic $SO_2$ treatments having concentrations ranging from 0.08 to 0.44 ppm $SO_2$ and total hours of treatment of approximately 10 to 117. While $SO_2$ dose is not a perfect parameter to use for quantifying $SO_2$ exposures, we have found it to be the most useful in summarizing the results of experiments using multiple $SO_2$ exposures at subacute concentrations. It can be seen that the yield response to doses of 10 ppm·hr and less is highly variable. At $SO_2$ doses of greater than 10 ppm·hr, there is some variability in the magnitude of the response but the yields were consistently reduced.

SERCLAP--NORTH CAROLINA STATE UNIVERSITY (PEANUT)*

Materials and Methods

Seeds of peanut (Arachis hypogea L.) 'NC-6' were inoculated with Rhizobium and planted with a 2 row planter in rows spaced 1 m apart on May 29, 1980. Soil analyses showed no need for fertilization. Plants emerged on June 3 and were thinned to one per 20 cm of row on June 12. Weeds were controlled by hand. Insects were controlled with Carbaryl (1 tbsp/3.8 liters) on July 2.

Due to the late arrival of equipment, the first exposure was delayed until August 28. The first exposures were performed at $SO_2$ flow rates that gave from 0.8 to 1.2 ppm in row 2 (downwind from the release pipe) to 0.04 to

* S. Cohen, R. B. Philbeck, and A. S. Heagle.

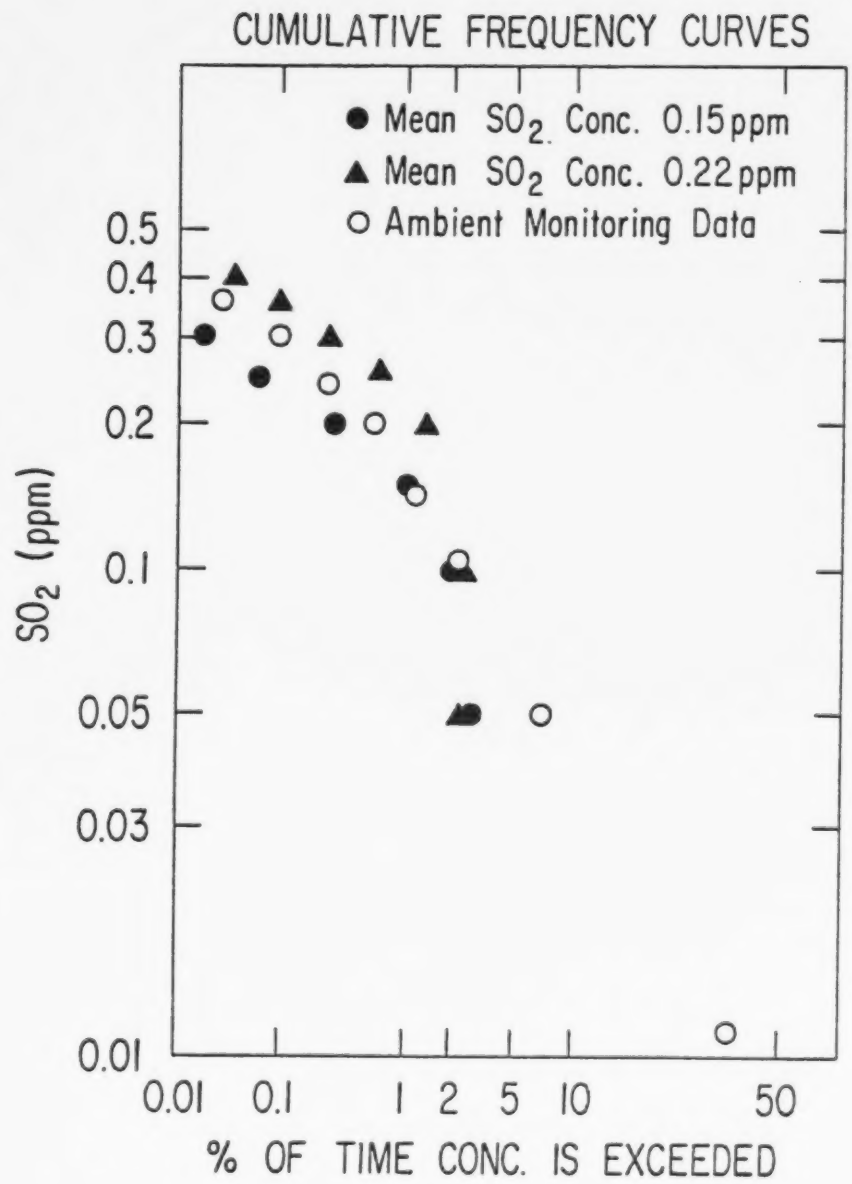


Figure 24. Cumulative frequency curves from rows 3 and 5 of the Corsoy soybean plot. The data was compiled during the inclusive period from the first until the last $SO_2$ treatment. The ambient monitoring data were taken from Loucks et al. (21).

TABLE 15. SUMMARY OF THE 1980 YIELD DATA FOR THE CORSOY AND WILLIAMS SOYBEAN PLOTS BY ROW

| Row* | Corsoy | | | Williams | | |
|---|---|---|---|---|---|---|
| | ($SO_2$) | Yield‡† | (% control) | ($SO_2$)† | Yield | (% control) |
| 1 | 0.38 | 846# | (87) | 0.40 | 828# | (80) |
| 2 | 0.31 | 805# | (82) | 0.31 | 892§ | (86) |
| 3 | 0.24 | 858# | (88) | 0.22 | 947§ | (91) |
| 4 | 0.20 | 963 | (99) | 0.18 | 921 | (89) |
| 5 | 0.16 | 1050§ | (108) | 0.14 | 892# | (86) |
| 6 | 0.13 | 1091§ | (112) | 0.12 | 985 | (95) |
| 7 | 0.11 | 963 | (99) | 0.11 | 1063# | (102) |
| 8 | 0.09 | 979 | (100) | 0.09 | 897# | (86) |
| 9 | 0.08 | 1058§ | (108) | 0.08 | 990 | (95) |
| Control | <0.01 | 976 | -- | <0.01 | 1038 | -- |

* Rows are numbered in the prevailing downwind direction from the $SO_2$ release pipe.

† Arithmetic mean $SO_2$ concentrations (ppm) during fumigation periods.

‡† Values are the mean dried bean weights of four 5 m row segments in grams. Control values are the mean of sixteen 5 m row segments.

§ Significantly different from the control at the 5% level.

# Significantly different from the control at the 1% level.

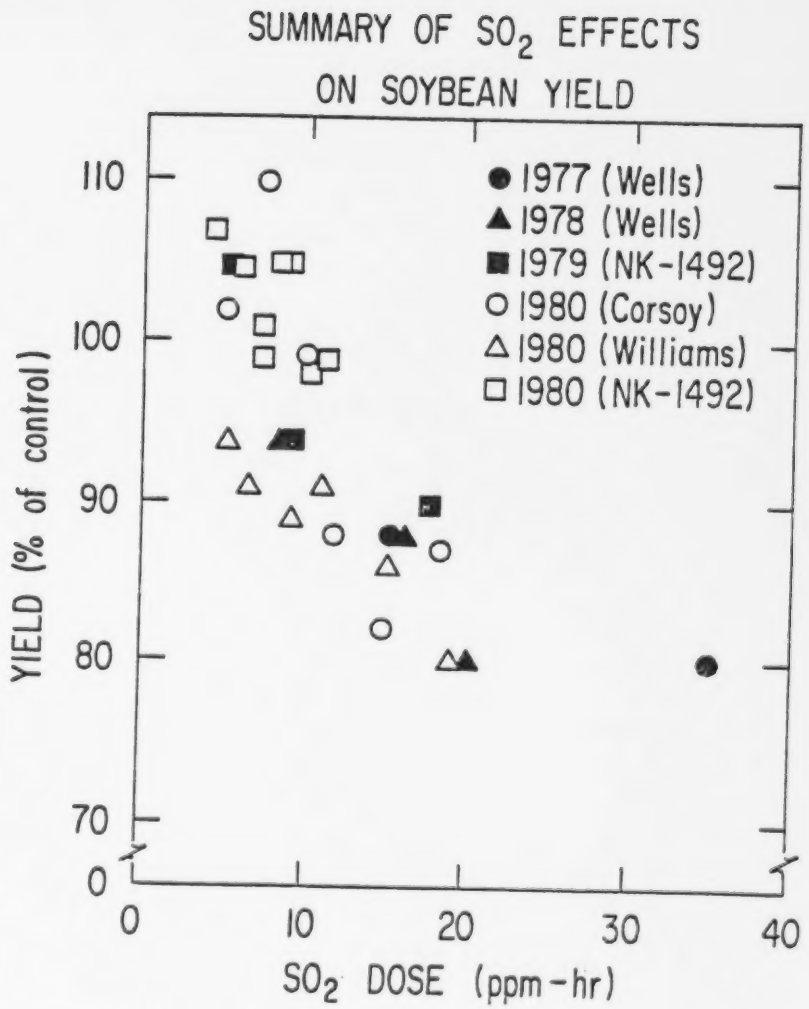


Figure 25. Summary of 4 years of $SO_2$ effects data with four cultivars of soybeans.

0.14 ppm at row 8 for both replicates. The last three exposures were performed at flow rates that gave from 2.3 ppm at row 2 to 0.5 ppm at row 8 in both replicates.

After every fumigation each of four 5-m subplots per row was examined for injury to the quadrifoliate leaves. If injury occurred, an estimate was made of the percent chlorosis and necrosis of leaves (whole plant estimates) at about every 40 cm in the 5-m subplots. Plants were harvested on October 16, 140 days after planting. A sample consisted of two adjacent plants taken from each of the four subplots in fumigated rows numbers 1, 2, 4, 6, and 8 and from rows 2 and 3 of the control rows. The roots and pods were washed free of soil before removing pods. All pods greater than 1 cm long were placed in coarse mesh plastic bags and air-dried for 13 days before weighing. Fresh weights of shoots and roots were recorded immediately.

## Results

The first foliar injury was seen 3 days after the third exposure. Injury occurred on scattered plots in row 1 and on 2 subplots in replicate 2. Downwind orientation (rather than horizontal) of some release holes was probably the cause of this injury. Three additional exposures caused no further injury. One of the few measurable rains occurred between the sixth and seventh exposure. This coupled with increase in $SO_2$ concentration was probably the reason for severe foliar injury in rows 1 and 2, moderate injury in rows 3 and 4, and scattered slight injury in the upwind side of row 5. No injury occurred in rows 6 through 10 or in the control rows. Where severe injury occurred, the first 6 to 12 quadrifoliate leaves (from terminal leaf down) were affected. The total injury leaf area was usually greater on the exposed terminal leaves with decreasing injury gradient toward the lower leaves. Even when the quadrifoliate leaves showed over 75% of the total leaf area injured, the amount of bronzing of individual leaflets often ranged from trace spotting of one leaflet to a maximum of 100% of the area for others. The last two exposures did not cause further injury.

The harvest data (Table 16) were not analyzed. The percent reduction in shoot weight from the controls was 20% in row 1 and 11% in row 2. The reduction in total pod weight from the check was 63% in row 1 and 30% in row 2. There was no decrease in root weight.

## Discussion

The weight and quality of pods and peanuts in this test was extremely low compared with that in a concurrent irrigated open-top field chamber test. This was due to an extremely dry period during July and August. Rainfall in July and August was 44% and 16% respectively of the 30 year average. The control plots yielded 225 pods, but only 42% of them were of normal size and only 12% had nuts of marketable quality. In the nearby irrigated plots, over 90% of the pods yielded marketable nuts. Therefore, in future tests it is recommended that plots be watered as needed to prevent water stress.

TABLE 16. GROWTH RESPONSE OF PEANUTS TO $SO_2$ EXPOSURES (ZAPS, 1980)

| Treatment | Row No. | Fresh weight per plant -- g* | | |
|---|---|---|---|---|
| | | Root | Shoot | All Pods |
| Control | 2 | 28.2 | 1948 | 266 |
| | 3 | 26.9 | 1821 | 253 |
| Exposed | 1 | 31.2 | 1501 | 97 |
| | 2 | 27.2 | 1685 | 181 |
| | 4 | 30.4 | 2087 | 275 |
| | 6 | 30.4 | 2068 | 211 |
| | 8 | 27.7 | 2055 | 271 |

* Each value is the mean of 16 plants (two from each of four subplots in each of two replicates).

NERCLAP--BOYCE THOMPSON INSTITUTE (BEAN)*

Methods and Materials

Two ZAPS were employed in 1980. One, designated West ZAPS, was used with the 'Redcloud' cultivar of red kidney bean and the other, East ZAPS, was used with the 'California Light Red' cultivar. Both ZAPS were initially positioned in such a manner that a south wind would distribute the pollutant and generate the gradient. The exposure system was first tried on July 21, 1980, 38 days after planting. Due to a malfunction in the monitoring system, the $SO_2$ concentration reached a high level and produced visible foliar injury on nearby plants. The ZAPS were then reoriented to allow fumigation to be conducted with a north wind. The plants which were injured in the initial ZAPS fumigation were located out of the zone of influence of the final ZAPS placement.

The exposure schedule for ZAPS consisted of two 3-hour fumigations per week. The exposures were conducted during periods in which the wind speed was between 4.8 and 16.0 km/hr and the wind direction was within 45° of being perpendicular to the release pipe. These constraints on wind speed and direction insured that the entire study plot would receive the $SO_2$ exposure and that the desired rate of pollutant dispersion and dilution would occur. All exposures were conducted between 0800 and 1600 EDT.

Exposures in the ZAPS were initiated on July 25, 1980, 42 days after planting. If wind shifts forced the termination of an exposure, it was resumed at the earliest opportunity. The final $SO_2$ exposures occurred on September 15, 94 days after planting.

The $SO_2$ monitoring in each ZAPS was conducted on a time-sharing basis using a system similar to that previously described for the open-top chambers. Scanivalve advancement was manually controlled. All monitoring was conducted with Thermo Electron Corporation Model 43 $SO_2$ monitors (Thermo Electron Corporation, Hopkinton, Massachusetts. Monitoring data were recorded on Datamart Model 755-M-M (Datamart Inc., Costa Mesa, California) strip chart recorders. All sample lines in the system were of Teflon. Separate monitoring systems were used for the east and west ZAPS.

Harvest of the bean in the ZAPS began on October 14, 1980. Harvests in the west and east ZAPS were initiated 123 and 127 days after planting, respectively. Each row to be harvested was divided into 20, 1-meter segments. The number of plants in each segment was determined and all pods which contained beans were collected. The pods were counted and separated into mature and green classes. No other data were collected for green pods, since they contained immature beans which would not be included in a marketable harvest. The mature pods were dried for 24 hours at 30°C, threshed by hand, and the beans weighed. The moisture content of the beans after drying was approximately 10%.

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* Robert Kohut, John Laurence, Luke Colavito.

## Results

Ambient $SO_2$ concentrations were measured at the ZAPS site from July 20 through September 11. The highest 1-hour average was 0.060 ppm on August 28. The highest instantaneous peak, 0.100 ppm, and 24 hour average, 0.022 ppm, $SO_2$ concentrations were also recorded on August 28. No $SO_2$ was detected on 31 of the 54 days on which monitoring was conducted.

The $SO_2$ monitoring data collected from ZAPS fumigations were analyzed to characterize the pollutant exposures. During the ZAPS study, exposures were conducted on 16 days. The 3-hour average $SO_2$ concentrations at the monitoring point closest to the release pipe in the east and west ZAPS was 0.31 and 0.33 ppm, respectively.

Observations of plant health were conducted throughout the exposure period. Particular attention was paid to the detection of $SO_2$ injury. None of the plants examined showed any signs of foliar $SO_2$ injury. Routine observation of the plants for color, growth, vigor, and phenology did not reveal any differences attributable to $SO_2$ either within the exposure gradient area or between exposed and control plants. Since the plants in the ZAPS exposure were receiving ambient levels of $O_3$, they were also examined for foliar $O_3$ injury. None of the plants examined either within or outside the area of $SO_2$ exposure showed any foliar $O_3$ injury. A survey of the weeds, including ragweed which developed in the ZAPS, did not detect any foliar injury attributable to $SO_2$ or $O_3$.

The plants which had been injured in the acute $SO_2$ exposure continued to grow throughout the study. Within a few weeks, it was difficult to identify the rows and specific plants which had been affected by the exposure due to the rapid growth which the plants were undergoing. No noticeable differences in vigor, development, or general appearance between the injured and uninjured plants were evident at the time the plants had reached their maximum growth.

The relationship between crop yield and $SO_2$ exposure in ZAPS was evaluated by regression analysis. The $SO_2$ exposure doses for the eleven monitoring points in each ZAPS were determined. The crop yield values associated with each monitoring point was the mean dry weight yields from the two 1-meter plots on either side of the monitoring point. The analysis indicated that there was no relationship between $SO_2$ dose and yield of beans in either the east or west ZAPS.

The impact on yield of the initial $SO_2$ exposure which produced acute foliar injury was also evaluated. Dry weight yields from 1-meter sample plots in two rows which had shown acute foliar injury in July and from two rows of control plants were not significantly different.

## SECTION 7

## EFFECTS OF MIXTURES OF SULFUR DIOXIDE AND NITROGEN DIOXIDE ON CROP YIELD (CSRCLAP)*

Argonne National Laboratory (CSRCLAP) did this mixture study using the ZAPS experimental design. The purpose of the study was to determine the effects of $SO_2$ and $NO_2$ in combination on a field-grown crop in the presence of ambient concentrations of $O_3$.

### MATERIALS AND METHODS

Soybean seeds [Glycine max (L.) Merr. cv. 'Northrup King' 1492) were planted on 15 May 1980 using standard agricultural practices. After emergence of the seedlings, field plots were selected for uniformity of slope, drainage, and seedling establishment. Three experimental areas were selected for pollutant exposures to $SO_2$ alone, $NO_2$ alone, and $SO_2$ + $NO_2$ combined.

The plots were fumigated on 10 occasions between July 30 and August 30, 1980, with an average exposure time per exposure of 2.5 hours for $SO_2$ and 2.9 hours for $NO_2$. Pollutants were released only on days with a southerly wind of adequate velocity to disperse the gases. Two air sampling lines for monitoring $SO_2$ concentrations were located 10 m apart in the center of rows 2, 5, 8, and 11, while $NO_2$ was monitored at one point in the center of each of those rows (Figure 26). The $SO_2$ concentrations during exposure periods were determined at each sampling point with a Meloy Laboratories model SA285 sulfur analyzer for 3-minute periods of every 24 minutes of exposure time, while $NO_2$ concentrations were measured using a Teco model 14 D/E, NO, $NO_2$, $NO_x$ monitor for 2-minute periods of every 16 minutes. The exposures resulted in total $SO_2$ doses ranging from 10.6 ppm hour in the row closest to the release pipe to 3.5 ppm hour in the experimental row farthest downwind from the pipe. The respective $NO_2$ doses ranged from 10.2 ppm hour to 3.3 ppm hour (Table 17). The maximum 3-minute $SO_2$ concentration measured was 1.02 ppm, while the maximum 2-minute $NO_2$ concentration was 1.41 ppm. The average concentrations during exposures were 0.42 to 0.14 ppm of $SO_2$ and 0.37 to 0.12 ppm on $NO_2$. Average ambient $SO_2$ and $NO_2$ concentrations were < 0.01 ppm. The 12 hour mean concentration of ambient ozone during July and August was 0.05 ppm and ranged from 0.02 to 0.09 ppm with peaks exceeding 0.1 ppm on six occasions.

The plants were observed regularly for signs of visible injury and a systematic examination of 40 plants per plot was made on August 29 to quantify injury. On September 3, the middle leaflet at the fifth node from the apex was removed from 20 plants per row in rows 2 and 5 from each fumigated plot and 20 plants from each control plot for chlorophyll assay. Chlorophyll was

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* Patricia M. Irving, Patricia B. Xerikos, and Joseph E. Miller.

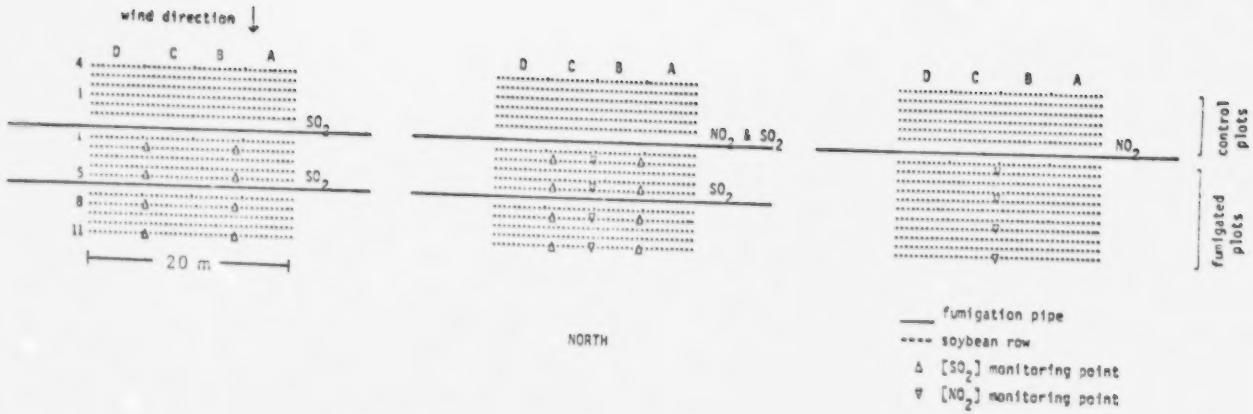


Figure 26. Experimental field design for $NO_2$ + $SO_2$ exposure.

TABLE 17. YIELD OF SOYBEANS AFTER 10 FIELD EXPOSURES OF $SO_2$, $NO_2$, AND COMBINATIONS OF THE TWO IN THE PRESENCE OF AMBIENT OZONE*

| $SO_2$† | | $NO_2$‡ | | Yield as %§ of control | Ratio of $SO_2$:$NO_2$ |
|---|---|---|---|---|---|
| ppm// | ppm hr# | ppm// | ppm hr# | | |
| <0.01 | <0.25 | <0.01 | <0.29 | 100.0 bcd (control) | 0.08 |
| 0.32 | 0.8 | | | 105 ab | |
| 0.26 | 6.5 | | | 101 abcd | |
| 0.20 | 5.0 | | | 105 ab | |
| 0.14 | 3.5 | | | 107 a | |
| 0.42 | 10.6 | | | 99 bcde | |
| 0.36 | 9.3 | | | 98 bcde | |
| 0.31 | 8.0 | | | 105 ab | |
| 0.26 | 6.6 | | | 99 bcde | |
| | | 0.37 | 10.2 | 99 bcde | |
| | | 0.31 | 8.9 | 97 cde | |
| | | 0.27 | 7.7 | 94 de | |
| | | 0.23 | 6.4 | 99 bcde | |
| | | 0.15 | 4.2 | 104 abc | |
| | | 0.14 | 3.9 | 105 abc | |
| | | 0.13 | 3.6 | 108 a | |
| | | 0.12 | 3.3 | 99 bcde | |
| 0.24 | 5.8 | 0.31 | 8.6 | 91 ef | 0.8 |
| 0.21 | 5.1 | 0.28 | 7.8 | 87 fgh | 0.8 |
| 0.18 | 5.1 | 0.25 | 7.0 | 86 fgh | 0.7 |
| 0.15 | 4.4 | 0.22 | 6.1 | 89 fg | 0.7 |
| 0.41 | 3.7 | 0.16 | 4.4 | 85 gh | 2.5 |
| 0.33 | 8.1 | 0.15 | 4.1 | 84 gh | 2.2 |
| 0.25 | 6.2 | 0.14 | 3.8 | 83 h | 1.8 |
| 0.18 | 4.3 | 0.13 | 3.5 | 82 h | 1.3 |

* 0.05 ppm mean 12 hour $O_3$ concentration.

† Average 2.5 hours per exposure.

‡ Average 2.9 hours per exposure.

§ Values followed by the same superscript are not significantly different, $\alpha = 0.05$, according to Duncan's Multiple Range Test.

// Mean concentration during exposure period.

# Total dose for 10 fumigations.

extracted with ethanol following Knudson et al. (22) and the absorbance value of the extract was converted to chlorophyll content of the leaf on a dry weight basis.

The center 20 m of rows 2 to 5 and 8 to 11 of the exposures plots and all four rows of the control plots were harvested in 5-m segments on September 30, October 1, and October 2, 1980. Seed weight for each 5-m row section was determined after drying at 65°C to constant weight. Analyses of variance were used to determine effects. Statistical significance of effects was determined according to Duncan's Multiple Range Test at the 0.05 level.

## RESULTS AND DISCUSSION

There was no statistically significant decrease in seed yield of soybeans after exposure to $SO_2$ alone or $NO_2$ alone at the doses used (Table 17). Yield was 7% higher ($p = 0.05$) than untreated plots in $SO_2$ exposed plots receiving the lowest dose (3.5 ppm hour) and 8% higher ($p = 0.05$) in $NO_2$ exposed plots receiving 3.6 ppm hour (second lowest dose). However, combinations of $SO_2$ and $NO_2$ decreased seed yield by 9 to 18% at concentrations causing no decreases when they occurred alone (Table 17).

Sulfur dioxide doses used in the 1980 study were similar to and lower than doses used on the same and different cultivars in previous experiments. A comparison of the studies suggests that the 'Northrup King' 1492 cultivar is slightly less sensitive to $SO_2$ than 'Williams' and probably of equal sensitivity as 'Corsoy.' Environmental conditions in 1980 compared to 1979 (Miller et al., 1979) apparently did not influence the response of "Northrup King" to $SO_2$ as yield effects were approximately the same at similar doses both years.

When examined on August 29, 1980, a greater number of plants in the combined plot exhibited interveinal chlorosis as compared to the single pollutant plots (Table 18). Leaf bronzing at the sixth node and below was observed in untreated and fumigated plots and was apparently the result of $O_3$ injury. Chlorophyll extraction of leaves collected on September 3 indicated no significant effect from $SO_2$ alone, little or no effect from $NO_2$, and approximately a 23% decrease from the combination of $SO_2$ and $NO_2$ (Table 18). These results suggest that the yield decreases resulting from exposure to $SO_2$ and $NO_2$ combined may have been caused by accelerated senescence. A greater degree of chlorosis was visibly evident in the combined plots as compared to the control and single pollutant plots in early September. Several investigators have reported visible injury to plants following exposure to combinations of $SO_2$ and $NO_2$ when no such injury occurred at similar concentrations of the pollutants alone (23, 24).

TABLE 18. EFFECTS OF $SO_2$, $NO_2$, AND COMBINATIONS OF THE TWO ON INTERVEINAL LEAF CHLOROSIS AND LEAF CHLOROPHYLL CONTENT OF SOYBEAN

| | $SO_2$ | $NO_2$ | $SO_2 + NO_2$ |
|---|---|---|---|
| % of plants exhibiting chlorosis* | 7.5 | 5.0 | 15.0 |
| Total chlorophyll (% of control)† | | | |
| Row 2 | 108 | 102 | 77‡ |
| Row 8 | 106 | 94‡ | 76‡ |

* Plants in rows 2-5 examined on 29 August 1980, n = 40, untreated plants showed no chlorosis.

† Leaves at fifth node from apex, sampled on September 3, 1980, n = 20.

‡ Effect is statistically significant at 0.05 level.

## SECTION 8

## SCREENING OF SELECTED SPECIES AND CULTIVARS FOR OZONE TOLERANCE--SWRCLAP*

Cultivar screening effort was undertaken to identify important cultivars of intermediate sensitivity to ozone. These will then be selected for full dose-response experiments in the open-top chambers.

Identical plantings were made at a site which receives a heavy dose of oxidant air pollution (Riverside Agricultural Experiment Station), and at a site which receives small doses of oxidant pollutant (the South Coast Experiment Station near Irvine, California). Seeds of selected cultivars were provided by the RCLAP's. Due to a delay in obtaining seeds this study could not be initiated until late June. Most of the crops should have been planted in early April for best results at Riverside.

Excessively high temperatures from mid June into July prevented establishment of wheat, timothy, brome grass, and clover stands at Riverside. These crops germinated and grew well at the South Coast Station, where temperatures were much cooler.

The crops were planted at recommended spacing in the row. Rows were 75 cm apart. Nitrogen fertilizer was placed in a band below the seed and after the plants had grown for about 6 weeks, a side dressing of nitrogen was applied. Furrow irrigation was used on all crops. Weeds were controlled by hand application of "Roundup" applied with a brush.

Photographs were made of the plots and photographs were made of some of the foliage symptoms where the injury was sufficiently severe to show in such pictures. The planting at both stations was examined every 2 weeks and a rating of foliage injury was recorded.

At harvest time subplots were identified by measuring 1.5 m from the end of the row to start measuring a section 3 m long from which production was recorded. A maximum of three subplots, each 3 m long, were harvested for each cultivar. In some cases insufficient seeds were supplied to plant rows long enough for such sampling. In such cases one or two subplots were used. The number of plants in each 3 m section was recorded and weight of marketable product was recorded. Table 19 presents the weight of product at both stations, percent difference, and a ranking based on difference in weight of the product.

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* O. C. Taylor.

TABLE 19. OZONE SUSCEPTIBILITY SCREENING TRIALS: HARVEST DATA AND ESTIMATED RANK OF CROPS INCLUDED IN THE $O_3$ SUSCEPTIBILITY SCREENING TRIALS AT THE SOUTH COAST AND RIVERSIDE EXPERIMENT STATIONS

| Crop | Variety | Measured Parameter | South Coast | UCR | % Difference | Rank |
|---|---|---|---|---|---|---|
| Corn | XL 32 AA | mean ear weight (g) | 299 | 245 | -18 | 5 |
| | Cornell 110 | | 277 | 182 | -34 | 4 |
| | Golden Queen | | 227 | 133 | -41 | 2 |
| | Silver Queen | | 239 | 156 | -35 | 3 |
| | Pioneer 3780 | | 212 | 185 | -13 | 7 |
| | NK 51036 | | 276 | 102 | -63 | 1 |
| | XL 72 AA | | 776 | 229 | -17 | 6 |
| | PX 443 | | 265 | 172 | -35 | 3 |
| Alfalfa | Vernal | yield per plant (g) | 24.6 | 8.2 | -67 | 3 |
| | Iroquois | | 34.6 | 9.9 | -71 | 2 |
| | WL-219 | | 50.9 | 14.7 | -71 | 2 |
| | WL-311 | | 41.7 | 24.9 | -40 | 5 |
| | Honeoye | | 33 | 13 | -61 | 4 |
| | DeKalb | | 47.7 | 11.9 | -75 | 1 |
| Birds Foot Trefoil | Empire | yield per plant (g) | 5.3 | 0.67 | -87 | |
| | Viking | | 4.2 | 0.64 | -85 | |
| Onion | Ebenezer Set | Bulb weight (g) | 138 | 68 | -51 | 2 |
| | White Lisbon Seed | | 43 | 19 | -55 | 1 |
| | 607 Ebenezer | | 32 | 27 | -16 | 4 |
| | Harvest More | | 55 | 32 | -42 | 3 |
| Potato | Kennebec | green weight per plant (g) | 182 | 264 | | |
| | Katahdin | | 26 | 374 | | |
| | Kennebec | tuber weight per plant (g) | 190 | 148 | | |
| | Katahdin | | 71 | 293 | | |
| Sorghum | 847 | grain weight per plant (g) | 165 | 137 | -17 | 4 |
| | 8815 | | 198 | 152 | -23 | 3 |
| | NK 2885 | | 212 | 117 | -32 | 1 |
| | NK 2778 | | 161 | 111 | -31 | 2 |
| | NK Savanna 5 | | 171 | 141 | -17 | 4 |
| Beans | Cal. Lt. Red | top weight per plant (g) | 98 | 45 | -54 | 2 |
| | Bush Blue Lake 47 | | 105 | 74 | -29 | 3 |
| | Redland | | 94 | 88 | -6 | 4 |
| | Provider | | 65 | 25 | -62 | 1 |
| | Cal. Lt. Red | pod weight per plant (g) | 59 | 19 | -68 | 2 |
| | Bush Blue Lake 47 | | 64 | 60 | -38 | 3 |
| | Redland | | 57 | 40 | -30 | 4 |
| | Provider | | 51 | 16 | -69 | 1 |
| Soybean | Wells | top weight per plant (g) | 111 | 80 | -28 | 6 |
| | Amsoy | | 136 | 89 | -35 | 5 |
| | Williams | | 147 | 63 | -57 | 1 |
| | Corsoy | | 129 | 57 | -48 | 3 |
| | Wayne | | 141 | 83 | -41 | 4 |
| | Woodworth | | 132 | 67 | -49 | 2 |
| | Wells | pod weight per plant (g) | 71 | 44 | -38 | 4 |
| | Amsoy | | 94 | 59 | -37 | 5 |
| | Williams | | 103 | 45 | -56 | 2 |
| | Corsoy | | 82 | 40 | -51 | 3 |
| | Wayne | | 94 | 61 | -35 | 6 |
| | Woodworth | | 99 | 39 | -61 | 1 |
| Tobacco | Speight G-28 | top weight per plant (g) | 2940 | 1086 | -63 | 3 |
| | Coker 347 | | 2909 | 768 | -74 | 1 |
| | Speight G-70 | | 2863 | 1014 | -65 | 2 |
| | Coker 319 | | 2798 | 1175 | -58 | 4 |
| | McNair 319 | | 2798 | 774 | -74 | 1 |
| | McNair 373 | | 3250 | 1522 | -53 | 5 |

(continued)

TABLE 19. (continued)

| Crop | Variety | Measured Parameter | South Coast | UCR | % Difference | Rank |
|---|---|---|---|---|---|---|
| Tobacco | Speight G-28 | leaf weight per plant (g) | 1531 | 656 | -57 | 5 |
| | Coker 347 | | 1629 | 484 | -70 | 2 |
| | Speight G-70 | | 1506 | 610 | -60 | 4 |
| | Coker 319 | | 1519 | 585 | -61 | 3 |
| | McNair 319 | | 1664 | 484 | -71 | 1 |
| | McNair 373 | | 1885 | 813 | -57 | 5 |
| Peanut | Florigiant | top weight per plant (g) | 575 | 376 | -35 | 2 |
| | NC 7 | | 675 | 307 | -55 | 1 |
| | NC 6 | | 556 | 428 | -23 | 4 |
| | NC 2 | | 564 | 421 | -25 | 3 |
| | Florigiant | peanut weight per plant (g) | 153 | 97 | -37 | 2 |
| | NC 7 | | 186 | 100 | -46 | 1 |
| | NC 6 | | 121 | 105 | -13 | 3 |
| | NC 2 | | 75 | 75 | 0 | 4 |
| Cotton | Coker 310 | weight per whole plant (g) | 229 | 332 | +45 | 4 |
| | Coker 304 | | 318 | -- | -- | - |
| | McNair 235 | | 278 | 352 | +27 | 3 |
| | McNair 220 | | 367 | 251 | -32 | 1 |
| | SJ 2 | | 322 | 342 | +7 | 2 |
| | Coker 310 | No. Flower + boll per plant | 9.1 | 16.8 | +85 | 3 |
| | Coker 304 | | 9.4 | 9.2 | -2 | 2 |
| | McNair 235 | | 6.0 | 13.6 | +127 | 4 |
| | McNair 220 | | 11.7 | 7.6 | -35 | 1 |
| | SJ 2 | | 4.6 | 10.6 | +130 | 5 |
| | Coker 310 | weight per 10' section (kg) | 4.2 | 6.2 | +48 | 4 |
| | Coker 304 | | 5.1 | -- | -- | - |
| | McNair 235 | | 5.8 | 5.0 | -14 | 1 |
| | McNair 220 | | 5.1 | 4.5 | -12 | 2 |
| | SJ 2 | | 6.2 | 6.2 | +3 | 3 |
| Tomato | 7718 VF | total yield (kg) | 54.0 | 33.4 | -38 | 9 |
| | Jetstar | | 52.2 | 33.8 | -35 | 10 |
| | New Yorker | | 36.9 | 15.8 | -57 | 7 |
| | Homesteid | | 54.4 | 14.2 | -74 | 6 |
| | Heinz | | 57.1 | 11.4 | -80 | 5 |
| | Campbell | | 64.7 | 34.3 | -47 | 8 |
| | Ace | | 54.8 | 6.0 | -89 | 4 |
| | Saturn | | 39.0 | 3.0 | -92 | 1 |
| | Manapal | | 70.3 | 6.7 | -90 | 3 |
| | Beefsteak | | 37.3 | 3.4 | -91 | 2 |
| | 7718 VF | yield per plant (kg) | 4.9 | 2.6 | -47 | 8 |
| | Jetstar | | 4.3 | 2.6 | -40 | 9 |
| | New Yorker | | 2.8 | 1.2 | -57 | 7 |
| | Homesteid | | 4.5 | 1.1 | -76 | 6 |
| | Heinz | | 4.8 | 0.8 | -83 | 5 |
| | Campbell | | 4.0 | 2.6 | -35 | 10 |
| | Ace | | 4.2 | 0.5 | -88 | 4 |
| | Saturn | | 3.5 | 0.2 | -94 | 1 |
| | Manapal | | 5.9 | 0.4 | -93 | 2 |
| | Beefsteak | | 2.9 | 0.3 | -90 | 3 |
| Oats | Astro | kg total weight per 10' section | 14.6 | 4.1 | -72 | 1 |
| | Orbit | | 10.9 | 4.2 | -61 | 2 |
| | Astro | g seed weight per 10' section | 1539 | 848 | -45 | 2 |
| | Orbit | | 1649 | 147 | -91 | 1 |

The following crops were not harvested, as their growth in Riverside was insufficient to obtain a good sample: wheat; timothy; brome grass; clover.

In considering the difference in yield and the relative rank given each of the cultivars, one should be aware that there is a marked difference between the Riverside and South Coast sites due to air temperature, relative humidity, soil type, and perhaps many other environmental factors. Difference in performance was probably affected by the marked difference in amount of air pollutants at the two sites, but it is certainly not due entirely to this one factor.

Table 20 is presented to indicate those cultivars which were ranked intermediate in $O_3$ susceptibility. Weight of product and estimated amount of visible injury were used in determining relative susceptibility rank.

TABLE 20. CULTIVARS CONSIDERED TO BE INTERMEDIATE IN SUSCEPTIBILITY TO AMBIENT OXIDANTS AT RIVERSIDE. PLANTS WERE RANKED AFTER CONSIDERING THE AMOUNT OF VISIBLE FOLIAGE INJURY AND EVALUATING DIFFERENCES IN YIELD

| | |
|---|---|
| Corn | Alfalfa |
| PX 443<br>Silver Queen<br>Cornell 110 | Vernal<br>Iroquois<br>WL-219 |
| Birds Foot Trefoil | Onion |
| No difference | Harvest More |
| Potato | Sorghum |
| Kennebec | NK 2778<br>B 815 |
| Beans | Soybean |
| Bush Blue Lake 47<br>Redland | Wells<br>Corsoy |
| Tobacco | Peanut |
| Coker 319<br>Coker 347<br>Speight G-70 | NC 6<br>Florigiant |
| Cotton | Tomato |
| McNair 235<br>Coker 310 | New Yorker<br>Heinz<br>Homestead |

SECTION 9

## DAMAGE ASSESSMENT AND DATA ANALYSIS-- BROOKHAVEN NATIONAL LABORATORY*

This initial effort at Brookhaven National Laboratory (BNL) requested by the NCLAN project office included five basic tasks: 1) install the original Benedict et al. (25) model on the Brookhaven computer; 2) rerun the 1969 data to prepared revised damage estimate; 3) update emissions and crop production information using 1974 data sets; 4) prepare 1974 damage estimates and compare with 1969 damage estimates; and 5) suggest modifications to improve modeling capabilities and reduce uncertainty.

Results from this study (31) suggest that national level damage due to oxidants increased between 1969 and 1974. It is difficult, if not impossible, to ascertain whether damage actually increased. Significant differences between data sets exist. These differences may not reflect actual changes in the environment, but rather discrepancies between the data bases used. The Benedict emission estimates, for example, are significantly lower than either the EPA or BNL estimates. Variations in losses between 1969 and 1974 relate primarily to these differences, but actual changes in emissions may not have occurred. Examination of EPA data, for example, suggests that nitrogen dioxide emissions increased, while hydrocarbon emissions decreased. How closely these data approximate actual field conditions remains to be seen. Geographically disaggregated data for specific counties and cities suggest both increases and decreases in measured ozone levels over this period. Since damage is estimated at the county level, increases in certain localities could in fact be plausible. More detailed review awaits development of detailed trend analyses of air quality at the county level.

Crop quantities were updated to 1974 for all of the enumerated crops except ornamentals. Because the methods of compilation of Benedict's 1969 and BNL's 1974 data are different, intracounty level comparisons between years and intercounty comparisons for a given year are suspect. State, regional, and national level estimates are better founded.

### UNCERTAINTIES AND NEEDED IMPROVEMENTS

Damage estimates produced by the Benedict modeling approach are associated with considerable uncertainty. Detailed evaluation and redefinition of specific parameters producing this uncertainty can substantially improve the

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quality of damage estimates. This initial effort suggests four areas of concern: damage functions, air quality estimates, yield data, and economic loss translation.

## DAMAGE FUNCTIONS

Benedict et al. (25) prepared subjective damage estimates for five economic effects classes and nine different oxidants exposure levels. These damage estimates enumerate expected decreases in plant productivity in terms of yield for each different plant type. Each plant within an economic effects class has the same expected response at equivalent air quality levels.

The accuracy of these damage functions is critical to the overall assessment. The Benedict damage functions represent the summation of a number of subjective judgments based largely upon foliar injury data. Little input from crop-yield data was used, principally because such data were not available. Furthermore, significant environmental variables were not included within the damage functions. As a result, the overall accuracy of the damage function is questionable.

## AIR QUALITY ESTIMATES

In the Benedict model, relative pollution levels are calculated by estimating emissions at the county level from fuel consumption data and integrating the emissions with dispersion coefficients from Holzworth. There are several problems with this approach. First, the Holzworth model was shown to contain an inherent error which could introduce additional uncertainty into the air quality estimates. Furthermore, the model provides only crude estimates of potential air quality impacts. Second, and perhaps more important, the pollution estimates are based solely upon the intracounty pollution generation potential; intercounty transport of pollutants is ignored. For oxidants, it is well established that intercounty transport plays a critical role in determining intracounty air quality. Counties having extensive agricultural production capacity may not produce significant quantities of oxidant precursors (nitrogen oxides and hydrocarbons), but may nevertheless experience oxidant problems because of pollution transport. Subsequent adverse impacts on plants could be expected and in fact are observed in the field.

Modeling capabilities need to recognize these differences. Models are presently being developed for oxidants, but are not available for this type of assessment. The simple alternative is to use air quality data collected by the EPA and other regulatory agencies. Although these measurements are generally based upon data collected in more urban settings, the intracounty variability with respect to oxidants is not great. Nevertheless, caution is necessary in extrapolating these data in time and space. For prospective studies, intercounty transport can only be captured through development and application of regional meterological dispersion and transformation models, but may be approximated by roll back techniques.

## YIELD DATA

Benedict et al. (25) developed their crop quantity and value estimates from published data and through personal communication. The BNL data base was updated with information published by the U.S. Department of Agriculture and the Census of Agriculture. This supplementary data set expands upon the 1969 crop coverage and thereby facilitates comparisons of inter-year and intra-year differences between the alternative data sets. Detailed reconstruction of Benedict's Ornamental group with 1974 numbers was beyond the scope of this project. Benedict's 1969 Ornamental values have, however, been included in the 1974 data set to facilitate between year rankings of value and loss by crop type.

## VALUING RANKING IN PRODUCTIVITY

The Benedict model estimates economic loss at the farm level. There is now considerable interest in development of more comprehensive estimates to include secondary costs. Major issues that need to be examined include consumer costs, effects of inter-regional competition, response to demand elasticities, and production substitution effects. Regional analyses incorporating many of these variables are presently being developed. Ultimately, linkages between these different modeling approaches must be developed to improve estimates of loss at the national level.

## CONCLUSIONS

The loss estimates presented in this report may not be accurate. Accuracy is affected by a large number of judgmental decisions that needed to be made, by error introduced within and between different data sets, and by the rough approach used to translate reductions in yield into economic losses. The values of this analysis lies therefore not in the exactness of the estimates themselves, but rather in the dissection and examination of a framework of analysis, estimation of the relative magnitude of the impact, identification of research needs and priorities, and identification of potential areas of geographic interest because of potential conflicts arising between vegetation and pollution.

Candidate issues in need of additional assessment include:

1. Development of probabilistic dose-response yield functions sensitive to changes in time and length of pollutant exposure, plant specific sensitivity, and other environmental parameters.

2. Identification of air quality statistics in spatial and temporal distributions useful to agricultural assessment models.

3. Updating 1969 and 1974 agricultural statistics with forthcoming 1978 Census of Agriculture data.

4. Integration of plant impact models with economic simulation modeling approaches to improve estimates of economic loss from air pollution.

5. Expanding crop production and air quality data sets to include all U.S. counties.

The overall success of the EPA program to establish coherent regulations depends upon the development of these data bases and modeling capabilities.

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